2003/2004 Analysis Coordinator Report

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1 Introduction

Similar to the years before this report completes the report 'Analysis Activities' published in the IGS Annual Report 2003/2004 (Gendt, 2005). A summary of the most important changes during 2003/2004 will be presented and the status of the product quality will be given. Many figures summarizing combination statistics on orbits, clocks and Earth Rotation Parameters (ERP) are shown, where most of the plots can be retrieved from the IGS Analysis Coordinator web-page at http://gfz-potsdam.de/igsacc.

The IGS Workshop and Symposium held in March 2004 in Bern (Meindl, 2004) passed a series of recommendations, which strived to consolidate and improve the quality of the IGS products. Among them was also the quality monitoring of the Precise Point Positioning (PPP) realization of the ITRF using the IGS Final and Rapid products, which demanded for larger additional activities in the combination process (see Section 7).

2 IGS products – Overview

The International GNSS Service is committed to provide the highest quality GPS&GLONASS observation data and products as the standard for global navigation satellite systems (GNSS) in support of scientific activities such as improving and extending the International Terrestrial Reference Frame, monitoring deformations of the solid Earth, variations in the liquid Earth (sea level, ice sheets, etc.) and in Earth rotation, determining orbits of scientific satellites, and monitoring the troposphere and ionosphere.

Table 1. Quality of the IGS Products as of December 2004
(for details see http://igscb.jpl.nasa.gov/ components/prods.html)

Product	IGS Final	IGS Rapid	IGS Ultra Rapid	
			Adjusted	Predicted
Updates	Weekly	Daily	4 times daily	4 times daily
Delay	~13 days	17 hours	3 hours	Real-time
GPS Orbits	< 5 cm	< 5 cm	< 5 cm	~ 10 cm
GPS Satellite Clocks	< 0.1 ns	0.1 ns	~0.2 ns	~ 5 ns
Station Clocks	< 0.1 ns	0.1 ns		
GLONASS Orbits	15 cm			
Polar Motion /LOD	0.05 mas	< 0.1 mas	0.1 mas	0.3 mas
LOD	0.02 ms/day	0.03 ms/day	0.03 ms/day	0.06 ms/day
Station Coordinates (h/v)	3 mm / 6 mm			
Ionospheric TEC grid	2-8 TECU	2-9 TECU		
Troposperic zenith path delay	4 mm		6 mm	

Table 1 gives an overview of the estimated quality of the IGS products at the end of 2004. With the CODE Analysis Center (AC) there is the first AC that provides combined GNSS – GPS & GLONASS – products (since June 2003).

The IGS is generating since several years Ultra Rapid products. The products comprises adjusted solutions (for a 24 hour data part) for orbits, ERPs and clocks, and predictions of those parameters for the next 24 hours.

3 Changes during 2003/2004 – Overview

Mid 2003 we had a smooth transition of the Analysis Coordination and the combination for the orbits/clock/ERP to the GeoForschungsZentrum Potsdam. An overview of all combination results and comparisons can be found at http://gfz-potsdam.de/igsacc.

The products of two new Analysis Centers, GOPE (Geodetic Observatory Pečny, Prague, Czech Republic) and MIT (Massachusetts Institute of Technology, Cambridge, MA, USA) were successfully validated over several months and are included in the official combination starting in 2004:

- GOPE contributes to the Ultra Rapid Products. Having one additional AC the quality and robustness of this IGS product is improved, and, because a minimum of 3 contributing ACs for each satellite is necessary especially the number of missing satellites could be reduced.
- MIT contributes to the Final Products. The large network of 150 stations used by MIT significantly improves the maintenance of the IGS network. Having for all of their stations a 5-min clock solution it is a valuable contribution to the IGS Time and Frequency Product.

Since March 2004 the clock results generated by the Clock Product Center (see https://goby.nrl.navy.mil/IGStime) are now directly used in all provided products. They provide a much better realization of the IGS time scale (see K. Senior, et al. this Volume). During the combination the raw clock products are submitted to the Clock Product Center and the combination is continued after the new RINEX clock (clk) and clock summary (cls) files are returned. The clocks included in the SP3 files will be taken from the new product, so that the SP3- and clk-files are consistent. The clock differences between all satellites and stations within one epoch are identical with the raw clock combination and therefore the PPP results are not affected. By this change the new clock products can now be downloaded from the IGS global data centers.

To get a better inside into the quality of the Ultra Rapid products the adjusted parts of the corresponding AC submissions and of the combined results are validated too. The results are distributed among the ACs in the summary reports for the Rapid and Ultra Rapid products. Since 2004 weekly IGS Reports are distributed to inform the user community about the Ultra Rapid product quality (IGSMAIL#4812). Since April 2004 the Ultra Rapid products are generated every six hours.

Since April 2004 CODE is now the second IGS AC, besides JPL, which is providing satellite clocks with a sampling rate of 30 sec. For the generation of a validated combined product still a third AC is missing and therefore all ACs are again requested to consider such a product.

Since August 2004 orbit products are provided in SP3-c format. The new format (see ftp://igscb.jpl.nasa.gov/igscb/data/format/sp3c.txt) includes error codes for orbits and clocks per epoch as well as flags of predicted parts (P) in the Ultra Rapid files. The file names have the extension ".sp3c". The new features are especially important for the predicted orbits, where, compared to the other IGS orbit products, a larger variation in the quality exists. For an

Table 2. Summary of changes during 2003/2004

GPS week	Date	Change
1223	2003-06-15	Switch of Rapid and Ultra Rapid Combination to GFZ
1231	2003-08-10	Switch of Final Combination to GFZ
1242	2003-10-26	Addition of the adjusted part of the Ultra Rapid orbits to the product validation
1250	2003-12-21	Distribution of weekly reports on the quality of the Ultra Rapid orbit predictions
1250	2003-12-21	Addition of MIT products to the Final Combination
1252	2004-01-04	Addition of GOPE products to the Ultra Rapid Combination
1253	2004-01-11	Introduction of new terrestrial reference frame realization IGb00
1261	2004-03-21	Products of the Clock Product Center are used in all Rapid and Final products
1267	2004-04-19	Ultra Rapid Combination repeated every 6 hours
1270	2004-05-10	Introduction of PPP validation
1283	2004-08-08	IGS products are distributed in SP3-c format (old format is kept for on overlapping time period)
1300	2004-12-05	Switch of GLONASS Combination to GFZ, name change from igx to igl
1304	2005-01-02	Exclude orbit parts from all products which are not covered by RINEX data from the IGS global network

overlapping time period both files, the new and the usual SP3 one (SP3-a format), will be available to allow for a smooth transition.

Since the end of 2004 the SP3-products are ‘cleaned’ in the sense that orbit information are removed from the SP3-file after a maneuver (the only exception is that an AC is providing a solution with the flag ‘M’) and for time intervals which are not covered by data; for that purpose the global IGS network is checked.

For the GLONASS combination the pilot phase has ended and the official products are offered since December 2004. Three ACs (COD, BKG, ESA) are contributing with analysis of GLONASS microwave data and one (MCC) with the analysis of laser data for 3 satellites. The later solution is used for validation only.

All changes are summarized in Table 2. Details of changes not touched yet will be given in Sections 6 and 7.

4 Reference Frame

Since the introduction of the terrestrial Reference Frame (RF) IGS00 ("IGS01P37_RS54.snx") in December 2001 the stability of its realization in the Rapid and Ultra Rapid products, where the RF defining stations are fixed, have been significantly improved. Additionally, an enlarged number of stations in the analysis and the ambiguity fixing introduced by some ACs contributed to the stabilization of the Rapid products.

Meanwhile, almost a dozen of the RF stations experienced problems and had to be removed from the list. To avoid a further deterioration in the RF realization it was decided to release an update of IGS00 with significantly more sites (~100). The new realization, called IGb00

("IGS03P33_RS106.snx"), was adopted in 2004 (GPS week 1253). There are no significant transformations between IGS00 and IGb00 (see R. Ferland, this Volume).

5 Atmosphere and Ionosphere Products

Since October 2003 the IGS Final ionosphere products are official now and they are distributed by the IGS Global Data Centers (for details see M. Hernandez, this Volume).

Since the beginning of 2004 the official IGS Final Tropospheric Products are based on a PPP using the official IGS Final orbits and clocks. The PPP technique allows the generation of this product for all the available stations in the global IGS network and enables also a efficient consistent reprocessing of historical data (at present the new products are available back to 2000; for details see Y. Bar-Sever et al., this Volume). Up to now for an overlapping period the 'classical' combined IGS Final Tropospheric Products are still available.

6 Product quality

Overall orbit quality

By the common efforts of all ACs the orbit quality could be enhanced during 2003/2004. Even for the already sophisticated Final and Rapid products improvements were reached, especially in the consistency among the contributing ACs. The orbit consistency among the best ACs is now at the level of 2-cm for the Finals (Table 3 , Figure 1) and 2-3 cm for the Rapids (Table 4, Figure 2). The combined IGS Rapid orbits differ by only 1 cm from the combined IGS Final ones. Significant progress can be stated for individual ACs, as ESA (GPS week 1243) and NGS (GPS week ~1292 and 1321) by their implemented changes, so that the majority of submissions is now converging at a high precision level.

A big progress has been obtained for the Ultra Rapid products by switching to a six hourly repetition in April 2004 (GPS week 1267). Most gain could be reached for the bad behaving satellites which are problematic in their predictions. The orbit predictions over the first 9 hours have reached the 5-cm level (Figure 3, top). The quality histogram for each single prediction shows that two third of the satellites can be predicted with 4 cm, most below 12 cm and only a few satellites, which have problems with their attitude control, show larger (>20cm) deviations (Figure 3, middle). Important is also that the product comprises the full satellite configuration. Nowadays in most cases no or only one satellite is missing (Figure 3, bottom).

For some applications the observed part of the Ultra Rapid products (named iga), being available with only a 3-hour delay, is also of interest. Their orbits differ to the Rapid ones by only 2 cm (Table 4) and are now validated regularly.

Orbit transformation parameters

In Table 3 to Table 5 the transformation parameters (translation, rotation and scale) between the individual AC products and the combined IGS products are summarized for the years 2003 until mid 2005. The corresponding time series of weekly mean values are given in Figure 4 to Figure 15.

No significant biases in translation and rotation can be seen for the combined products, and for most ACs too, and the values itself, with a precision of a few mm, correspond to the precision obtained for the station coordinates.

Compared to early years the scatter for the Final parameters is now smaller than for the Rapid ones, proving that the overall consistency in generating the Final products has improved. The only exception is NGS, but here we see also a significant improvement after major software changes at GPS week 1321 (Figure 5, Figure 7).

A few interesting effects should be mentioned. So, by its changes introduced in GPS week 1243 a large bias in the rotations at ESA could be solved. Larger fluctuations in the Final x and y rotations at MIT and SIO, which can also be observed in their pole solutions (see below), originate from some inconsistencies to their SINEX products. As the rotational biases from the SINEX combination are applied in the orbit combination process any inconsistency maps directly into the behavior of the orbits. In the x rotation for the Rapid SIO orbits a larger bias can be seen, which corresponds to a similar bias in the y pole component.

Even for the Ultra Rapid predicted orbits we have stable translation and scale values. Only their rotations, mostly affected by prediction uncertentiess for pole and LOD, have a larger scatter in the range of 0.3 to 0.5 mas.

There is an AC (software and technology) dependent scale bias in the orbits, reaching from -0.4 to +0.4 ppb. With a scatter of ±0.1 ppb or smaller these biases are significant and stable for most ACs. Some larger scatter can be found for the Final SIO and MIT orbits. Interesting is that the scale for SIO Final orbits differ significantly (~ +0.5 ppb) from its Rapid and Ultra Rapid values. A similar behavior, i.e. a scale difference between different analysis lines, can be found for the Ultra Rapid orbits from EMR (using Bernese instead of GIPSY) and USN. Compared to their Final or Rapid scale, differences of ~ -0.5 ppb and ~ -0.4 ppb, respectively, can be seen.

Earth Rotation Parameter

Some statistics on the ERP quality are given in Table 6, where all individual and combined series are compared.

Even now where the official IGS ERP product is generated during the IGS SINEX combination (see R. Ferland, this Volume) the ACs provide generating separate Final ERP files, which are combined in parallel with the orbits. These results are a good measure for the internal consistency of all the AC's submitted products. The overall differences of the here combined Final ERP to the "SINEX ERP" (named 'irf' in the table) show a scatter below 0.02 mas, 0.06 mas/d and 10 μs for pole, pole-rate and LOD, respectively. Major software improvements by ESA (GPS week 1243) and NGS (GPS week 1321) can be seen in Figure 16. A bias for MIT and larger fluctuations for SIO are caused by some inconsistencies to their SINEX submissions. A strong indication for that is that if one ignores the corrections for reference frame rotations given by the SINEX combination (which are intended to improve the consistency of the AC's submissions before combination) their agreement with the combined ERP is much better. Also their excellent pole-rate solutions indicate that the basic estimates are of much higher quality. Some LOD biases can be seen for EMR, ESA and MIT.

The IGS Rapid pole has, compared to the Final one, a scatter of 0.05 mas (~1-2 mm in the position on the surface) and no significant bias. For the rates, which can be better stabilized having neighboring days, an increase of the scatter by a factor of 2 can be stated from Final to Rapid (Figure 17,Figure 19). Larger LOD biases exist for EMR and USN (Figure 22).

Even for the Ultra Rapid pole the combined solution has, compared to the Rapid one, a scatter of only 0.07 mas (Figure 20). For GOP a bias in its y pole component and an uncorrected tidal LOD effect (Figure 24) as well as for USN a bias in the x pole component can be seen. Interesting to mention is that the Ultra Rapid pole-rate solutions for EMR (using Bernese instead of GIPSY) and SIO are better than their Rapid ones.

7 Precise Point Position Validation

As recommended at the IGS Workshop 2004 a PPP validation, based on the IGS Final and Rapid orbits and clocks, was introduced to check the stability of the IGS RF realization. The validation started in September 2004 (GPS week 1290), and for the Final products a reprocessing back to GPS week 1220 were added. The PPP is using all the ~100 stations defining the IGS RF (IGb00), and is running for the combined IGS Final and Rapid products as well as for the products from all the individual ACs. Residual plots for all individual station solutions after a Helmert transformation to IGb00 and to the weekly combined SINEX solutions are given on the web-page http://gfz-potsdam.de/igsacc. Compared to the weekly combined SINEX solutions the quality for the PPP station solutions based on combined IGS products is 2-4 mm and 5-8 mm in the horizontal and the vertical, respectively (Figure 25). The same comparisons to the IGb00 reveal similar seasonal effects as known from the network solutions; with the growing RMS over time they demonstrate also the degradation in the IGb00 quality.

It was further recommended that the Final clock solutions should be realized in a way so that the PPP will be in the IGb00 and not in the instantaneous geocenter system as defined by the satellite orbits. For this purpose the resulting station coordinates have to be aligned best to the IGb00 while solving for the satellite clocks. Comparing for the individual ACs the Helmert transformation parameters of PPP results with those from the SINEX combinations, where the geocenter is free in the AC submitted solutions, one can clearly see, which ACs deliver clock solutions consistent with their instantaneous geocenter (Figure 27, EMR) and which deliver clocks aligned to the IGb00.

Looking into the PPP translation parameters (Figure 26), one can see that the Rapid translations, where the ACs are fixing the RF IGb00 during their clock estimations, are often smaller.

8 Outlook

The relative phase center models introduced by 30 June 1996 (Neilan et al., 1996) and using the "AOAD/M_T" antenna as the defining standard have its limitations in being valid over short baselines and down to 10 degree elevation angle only. Therefore the IGS is discussing a switch to absolute calibrated antennas since the IGS Workshop in Ottawa. Those absolute models for GPS receiver antennas are available since several years and show a good consistency with values of the relative models. However, to avoid a scale bias in the Terrestrial Reference Frame its introduction has to be accompanied with compatible models for the satellite antennas. As recommended at the last IGS Workshop the satellite antenna models, compatible with the given receiver models and the RF IGb00 will be determined and tested until the end of 2005. It is expected that the new model will give no scale change in the terrestrial RF and especially no significant scale drift by changing satellite constellations, as it is the case with the present model (Ge et al., 2005). Because any change in antenna parameters may have a significant impact on derived station heights, those changes have to be prepared very carefully. The expected changes in the station coordinates will lead to an update in the IGS RF. At the same time the IGS will start to apply the available radome calibrations, which will results in station coordinate changes too. It is planned that in 2006 the new absolute model will officially be adopted.

A reprocessing of all IGS data since 1994 to generate homogeneous series of products based on the best models, parameters and analysis technologies is in preparation and will be an important task during 2006. This first concerted reprocessing by IGS ACs and other groups will lead to a new era in the IGS products, by providing on a regular basis new reprocessed time series after new models have been introduced.

Another two important fields the IGS will enter into during the near future are the provision of real-time data streams and products (see M Caissy, this Volume) as well as the generation of LEO products (H. Boomkamp, this Volume).

9 References

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10 Tables and Figures

Table 3. IGS Final Combination mean and standard deviation (σ) of daily transformation parameters (translation, rotations and scale), weighted orbit RMS and clock RMS (station and satellite clock biases removed). Based on GPS weeks 1200 to 1330 (01/2003 – 06/2005). The Rapid products (IGR) are also compared to the Final combined products.

AC		Days	Tx [mm]	Ty [mm]	Tz [mm]	Rx [mas]	Ry [mas]	Rz [mas]	Scale [ppb]	WRMS [mm]	CRMS [ns]
cod	Mean	917	1.5	0.0	0.2	0.03	-0.04	0.00	-0.38	15	0.044
	σ		1.3	1.6	5.4	0.04	0.03	0.03	0.08	2	0.009
emr	Mean	917	1.3	-0.4	-0.3	0.03	0.01	-0.00	0.35	20	0.051
	σ		2.2	2.5	4.3	0.07	0.08	0.05	0.06	4	0.084
esa	Mean	903	-0.8	1.4	-3.3	-0.06	0.02	-0.03	0.23	39	0.066
	σ		3.5	3.1	8.7	0.17	0.07	0.11	0.10	15	0.015
gfz	Mean	917	-0.6	-0.5	-1.0	-0.00	0.02	0.05	-0.23	17	0.036
	σ		1.7	2.3	3.5	0.03	0.04	0.07	0.07	2	0.009
jpl	Mean	914	-0.6	0.5	-0.5	-0.08	0.02	-0.00	0.21	34	0.039
	σ		4.4	4.4	6.1	0.11	0.06	0.06	0.09	5	0.009
mit	Mean	567	-2.5	0.6	2.7	-0.22	0.04	-0.04	0.24	28	0.042
	σ		3.7	2.4	5.1	0.10	0.11	0.06	0.17	5	0.038
ngs	Mean	917	-2.0	-2.3	12.0	0.10	-0.12	-0.05	-0.03	50	-
	σ		5.6	5.2	14.4	0.22	0.27	0.21	0.13	14	-
sio	Mean	909	-0.5	0.2	-4.6	0.10	-0.02	-0.04	0.23	45	-
	σ		3.3	3.6	9.6	0.16	0.15	0.08	0.24	10	-
igr	Mean	917	0.1	-0.8	-0.1	0.02	-0.01	-0.00	-0.07	13	0.039
	σ		1.6	1.8	3.1	0.03	0.03	0.03	0.07	2	0.009

Table 4. IGS Rapid Combination mean and standard deviation (σ) of transformation parameters, weighted orbit RMS and clock RMS. Based on GPS weeks 1200 to 1330 (01/2003 – 06/2005). For the Ultra Rapid predictions starting at 00 UT the 24 h adjusted (iga) and the 24 h predicted (igu) parts are also compared to the Rapid combined products.

AC		Days	Tx [mm]	Ty [mm]	Tz [mm]	Rx [mas]	Ry [mas]	Rz [mas]	Scale [ppb]	WRMS [mm]	CRMS [ns]
cod	Mean	917	0.5	0.1	0.8	0.03	-0.00	0.04	-0.36	21	0.052
	σ		1.9	2.4	5.4	0.05	0.06	0.06	0.07	3	0012
emr	Mean	865	2.9	-1.5	-1.6	0.04	0.00	0.00	0.45	37	0.049
	σ		3.5	3.5	7.1	0.08	0.07	0.07	0.07	13	0.019
esa	Mean	856	-0.7	2.3	-2.3	-0.05	0.04	-0.06	0.28	52	0.087
	σ		4.0	6.9	12.0	0.15	0.15	0.13	0.10	37	0.064
gfz	Mean	903	-0.2	0.4	1.5	0.00	0.01	-0.00	-0.14	21	0.045
	σ		2.2	2.0	4.0	0.06	0.06	0.05	0.06	12	0.014
jpl	Mean	836	1.1	0.6	-2.2	-0.01	-0.05	0.00	0.17	55	0.048
	σ		4.3	5.5	9.6	0.11	0.16	0.08	0.11	30	0.025
ngs	Mean	831	-1.0	-1.3	0.6	0.01	-0.07	-0.03	-0.09	47	-
	σ		4.8	4.8	8.6	0.15	0.13	0.12	0.16	20	-
sio	Mean	854	-4.7	-0.5	-2.2	-0.26	0.00	-0.01	-0.23	58	-
	σ		4.9	6.1	10.1	0.20	0.23	0.11	0.23	12	-
usn	Mean	904	-0.7	-0.4	-1.8	0.01	0.00	-0.02	0.27	26	0.055
	σ		3.1	3.4	5.9	0.05	0.06	0.08	0.09	6	0.026
iga	Mean	627	1.4	0.9	-0.0	0.02	0.01	0.02	-0.14	19	0.104
	σ		2.0	2.2	3.3	0.06	0.05	0.17	0.06	3	0.069
igu	Mean	917	0.5	1.1	-1.4	-0.02	0.02	0.13	-0.17	126	3.361
	σ		4.1	4.0	7.6	0.29	0.33	0.47	0.12	117	0.954

Table 5. IGS Ultra Rapid Combination (at 00 and 12 UT) mean and standard deviation (σ) of transformation parameters, weighted orbit RMS and clock RMS compared to the Rapid combined products (first 6 h of the predicted part). Based on GPS weeks 1200 to 1330 (01/2003 – 06/2005).

AC		#Val	Tx [mm]	Ty [mm]	Tz [mm]	Rx [mas]	Ry [mas]	Rz [mas]	Scale [ppb]	WRMS [mm]	CRMS [ns]
cou	Mean	1830	2.2	0.8	0.3	0.07	-0.00	-0.04	-0.34	63	6.28
	σ		14.2	13.0	9.9	0.32	0.37	0.51	0.17	63	1.35
emu	Mean	1795	1.5	1.0	-1.4	-0.02	-0.03	0.13	-0.13	96	3.26
	σ		14.3	12.9	12.7	0.27	0.27	0.37	0.24	93	1.17
esu	Mean	1657	-0.0	2.6	-4.3	-0.02	-0.03	-0.09	0.28	140	3.62
	σ		24.6	21.3	19.7	0.44	0.44	0.40	0.29	107	1.14
gfu	Mean	1786	1.3	2.1	1.9	0.21	-0.02	-0.00	-0.20	96	4.24
	σ		12.4	12.2	11.0	0.28	0.33	0.37	0.20	114	1.29
gou	Mean	1056	3.0	-0.8	-3.5	0.34	-0.06	0.15	-0.27	137	5.39
	σ		20.4	17.1	19.7	0.33	0.38	0.43	0.27	92	1.00
siu	Mean	1770	3.2	-0.3	-7.5	-0.15	-0.00	0.19	-0.13	152	-
	σ		23.1	26.5	18.0	0.46	0.49	0.53	0.31	125	-
usu	Mean	1675	2.0	2.0	3.0	-0.14	0.07	0.17	-0.09	137	3.35
	σ		21.0	19.2	14.4	0.40	0.44	0.51	0.28	59	1.35
igu	Mean	1827	1.8	1.4	-1.1	0.01	-0.01	0.17	-0.15	87	3.36
	σ		10.2	9.2	8.0	0.24	0.27	0.40	0.15	118	1.24

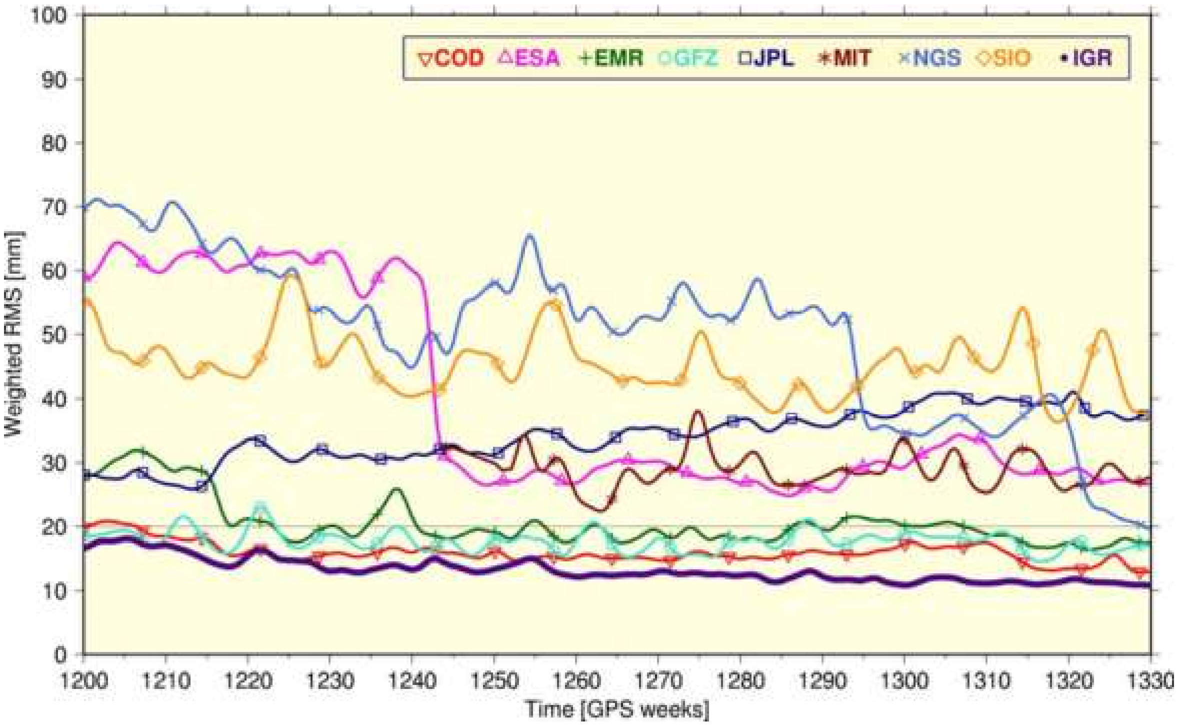
Table 6. Comparison (mean and standard deviation σ) of the IGS ERP Products (X-, Y-pole and their rates and LOD) based on GPS weeks 1200 to 1330 (01/2003 – 06/2005).

a: Difference of all individual Final time series to the combined Final product (irf is the official product from the SINEX Combination)

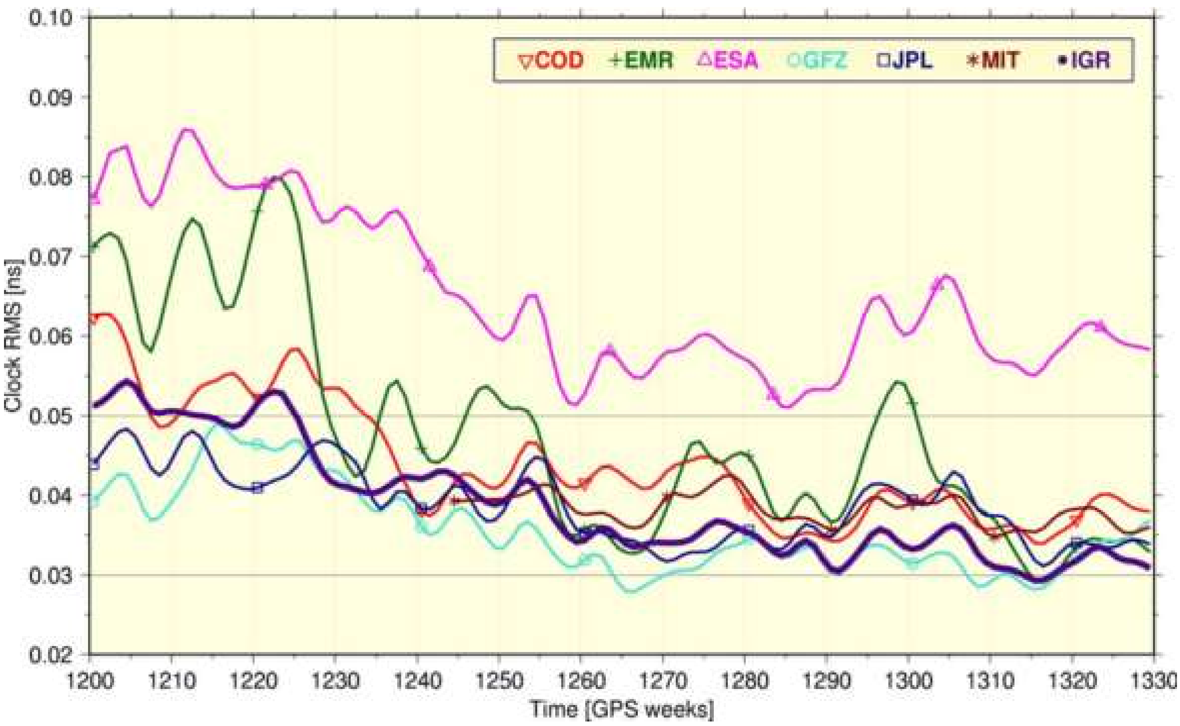
b: Difference of all individual Rapid time series to the combined Final product.

c: Difference of all individual Ultra Rapid time series (at 00 UT) to the Combined Rapid Product.

	AC	#Val	X-Pole [µas] Mean	σ	Y-Pole [µas] Mean	σ	X-Rate [µas/d] Mean	σ	Y-Rate [µas/d] Mean	σ	LOD [µs] Mean	σ
sFinal	cod	917	12	27	19	33	-6	79	11	84	10	12
	emr	917	0	48	19	43	-50	146	-42	185	-30	21
	esa	909	23	95	32	126	-0	132	9	145	-30	31
	gfz	917	-5	34	-42	44	25	100	14	82	-6	15
	jpl	917	6	35	-3	39	68	178	-29	133	-1	35
	mit	826	6	83	104	75	-5	100	7	103	-33	20
	ngs	917	12	187	-123	175	53	435	83	403	3	69
	sio	908	7	97	-45	95	-17	95	25	104	-20	25
	irf	917	6	17	-8	19	-1	63	8	62	0	10
Rapid	cod	917	-0	57	14	63	-17	142	16	144	8	12
	emr	867	21	89	44	103	45	318	-30	333	-40	21
	esa	835	68	178	43	161	182	332	-38	377	-19	49
	gfz	903	7	87	-21	78	65	183	4	181	-10	16
	jpl	837	-50	224	-8	158	-6	347	21	280	-10	43
	ngs	832	-35	168	-21	201	25	564	130	542	8	44
	sio	861	24	126	-155	126	-68	469	213	456	-9	34
	usn	905	9	88	4	75	-37	220	41	225	-46	27
	igr	917	5	52	-1	43	18	112	19	111	-0	10
Ultra	cou	916	-11	220	33	159	-59	321	14	252	13	55
	emu	915	-51	112	-77	130	-23	208	-4	217	1	35
	esu	883	30	252	62	253	38	869	-60	813	-	-
	gfu	913	29	167	-5	150	28	252	5	225	-10	20
	gou	616	-30	256	288	271	-74	279	-37	263	6	50
	siu	856	-81	318	-148	279	-42	386	-99	368	27	85
	usu	886	148	212	-7	191	145	414	122	392	-37	52
	igu	917	2	72	-6	73	-35	148	-16	144	-0	14

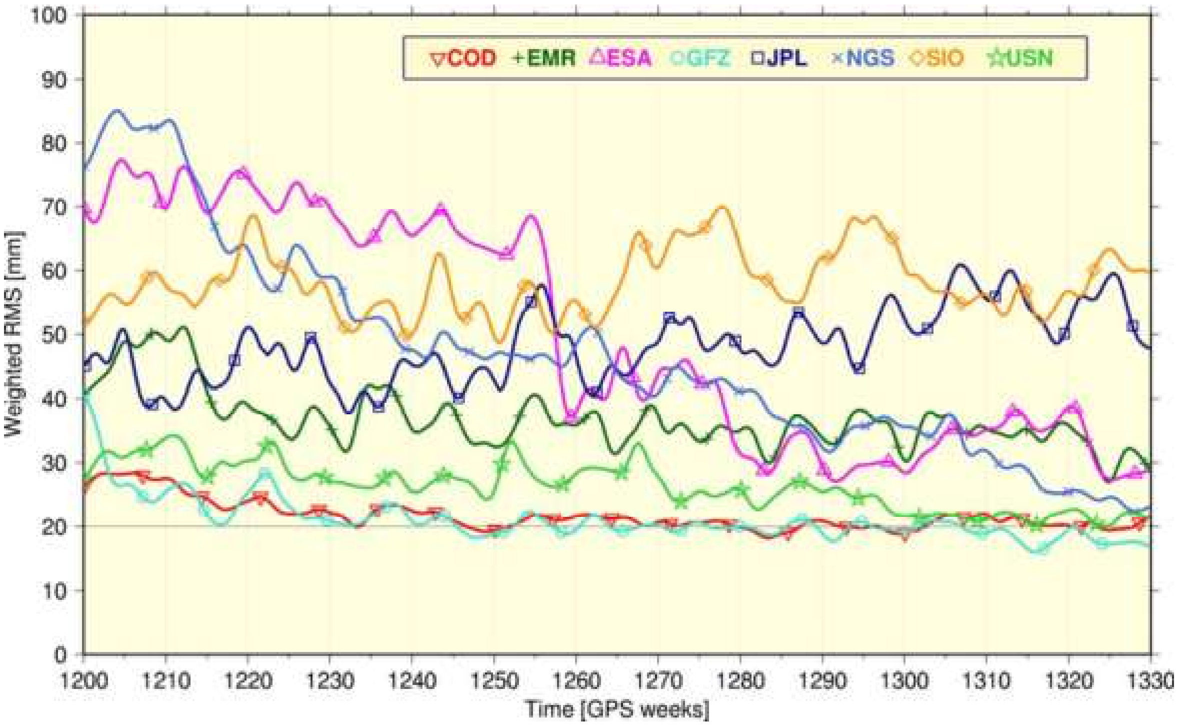


(a) Final orbits

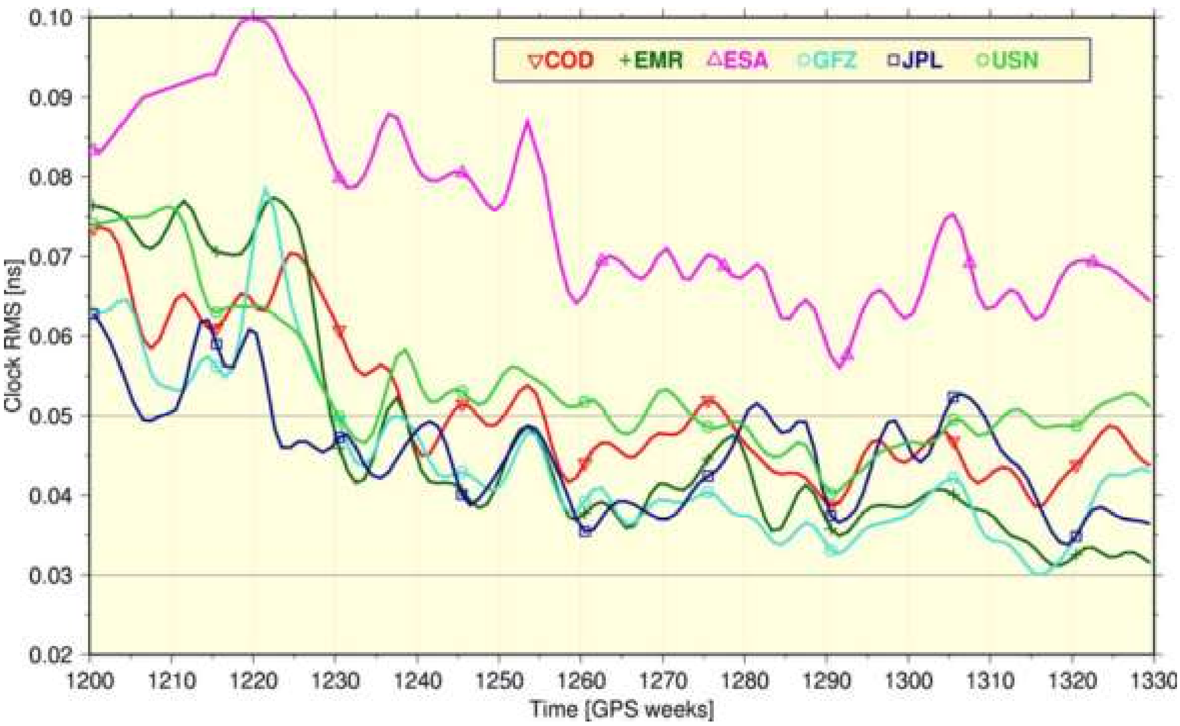


(b) Final clocks

Figure 1: Smoothed Final weighted orbit RMS [mm] and clock RMS [ns] of all ACs and IGS Rapid (IGR) compared to the Final Combination.



(a) Rapid orbits



(a) Rapid clocks

Figure 2: Smoothed Rapid weighted orbit RMS [mm] and clock RMS [ns] of all ACs compared to the Rapid Combination.

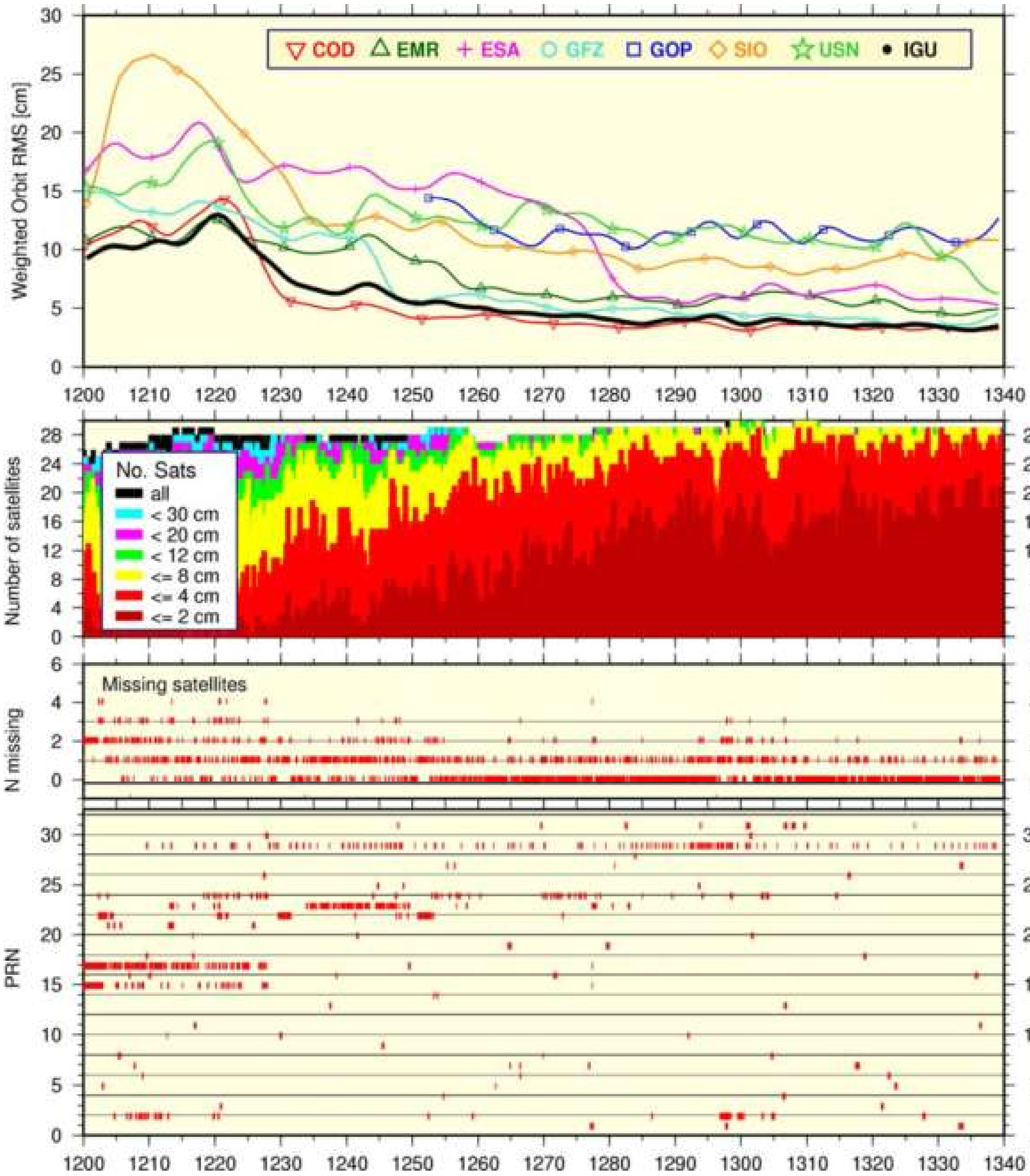


Figure 3: Smoothed Ultra Rapid weighted orbit RMS [cm] of all Analysis Center and IGS Ultra Rapid (IGU) solutions compared to the Rapid Combination (top), histogram for the prediction quality for each single product (middle), and number of missing satellites and each single missing satellite in the predictions (bottom).

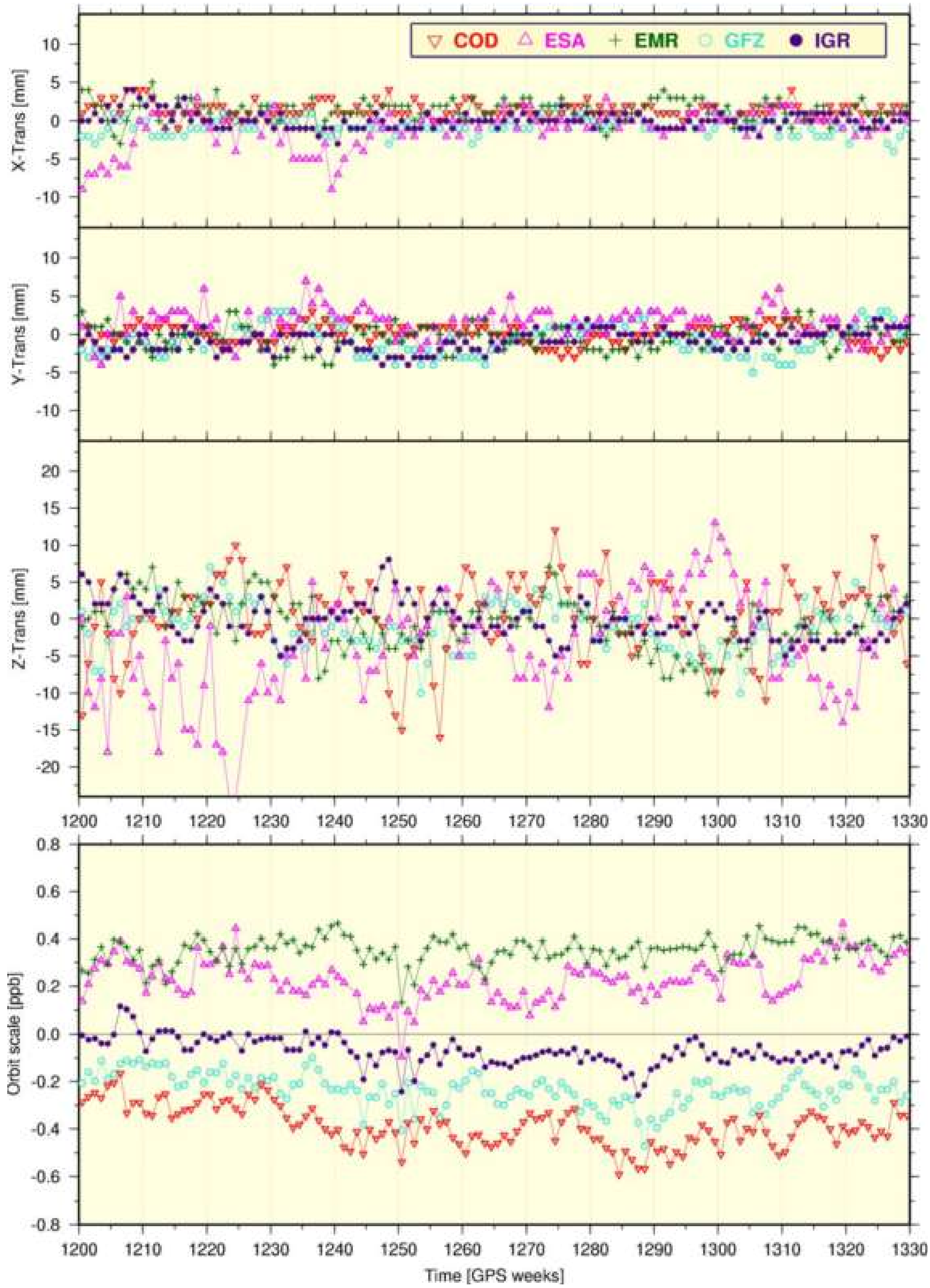


Figure 4:Weekly mean translation parameters and scale of the AC Final and IGS Rapid (IGR) orbits with respect to the IGS Final orbits (for ACs: COD, ESA, EMR, GFZ)

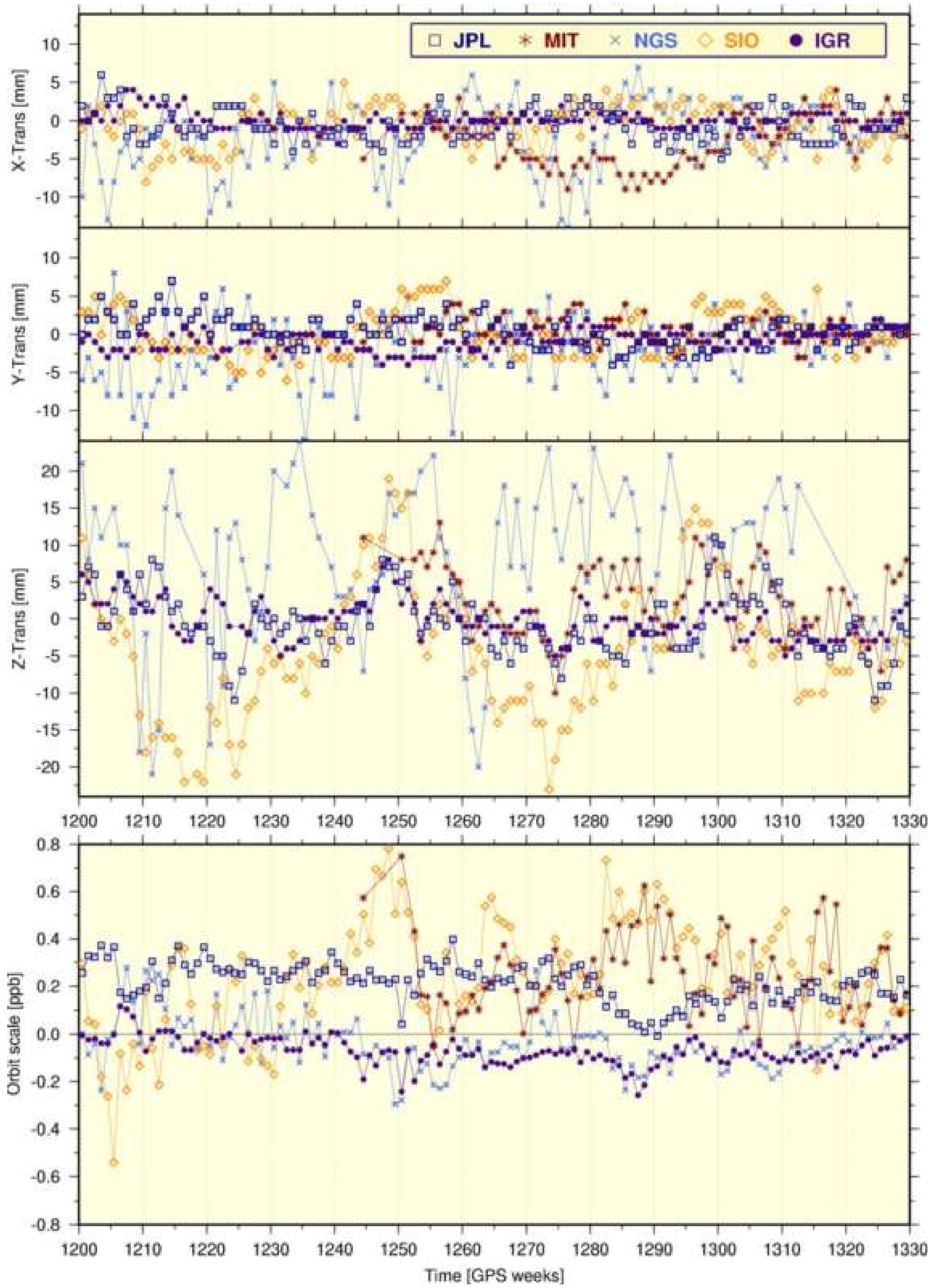


Figure 5: Weekly mean translation parameters and scale of the AC Final and IGS Rapid (IGR) orbits with respect to the IGS Final orbits (for ACs: JPL, MIT, NGS, SIO)

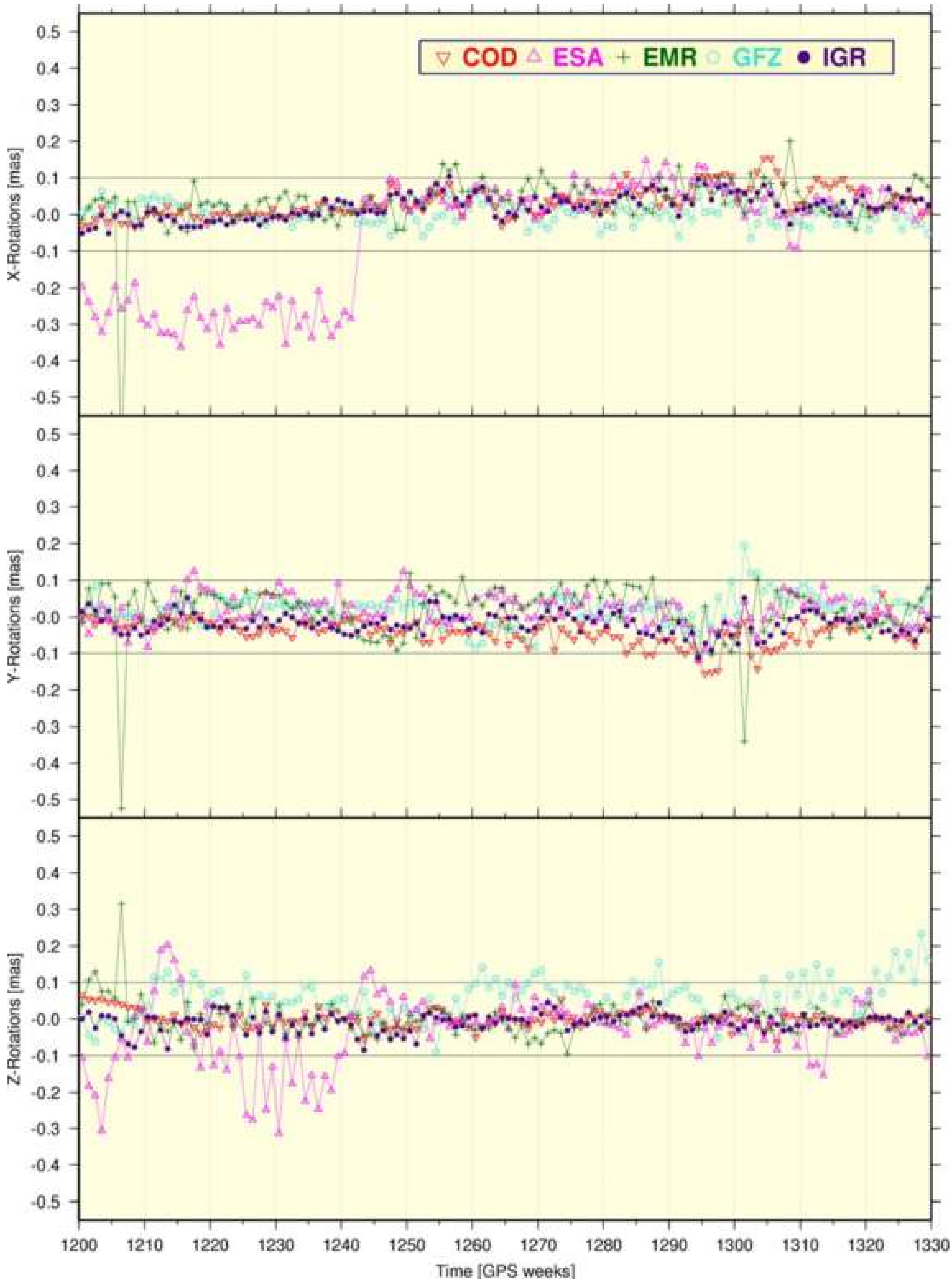


Figure 6: Weekly mean rotation parameters of the AC Final and IGS Rapid (IGR) orbits with respect to the IGS Final orbits (for ACs: COD, ESA, EMR, GFZ)

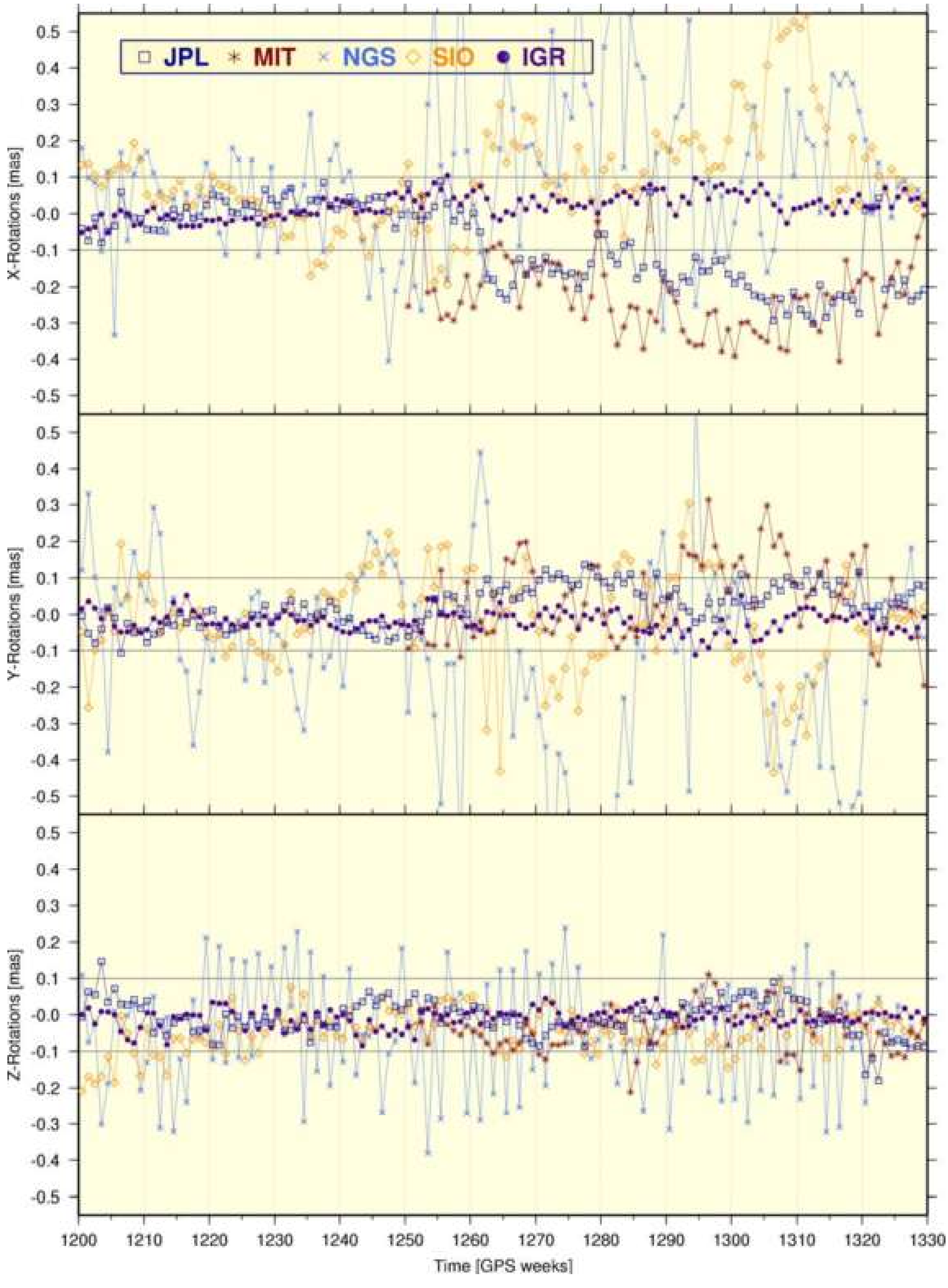


Figure 7: Weekly mean rotation parameters of the AC Final and IGS Rapid (IGR) orbits with respect to the IGS Final orbits (for ACs: JPL, MIT, NGS, SIO)

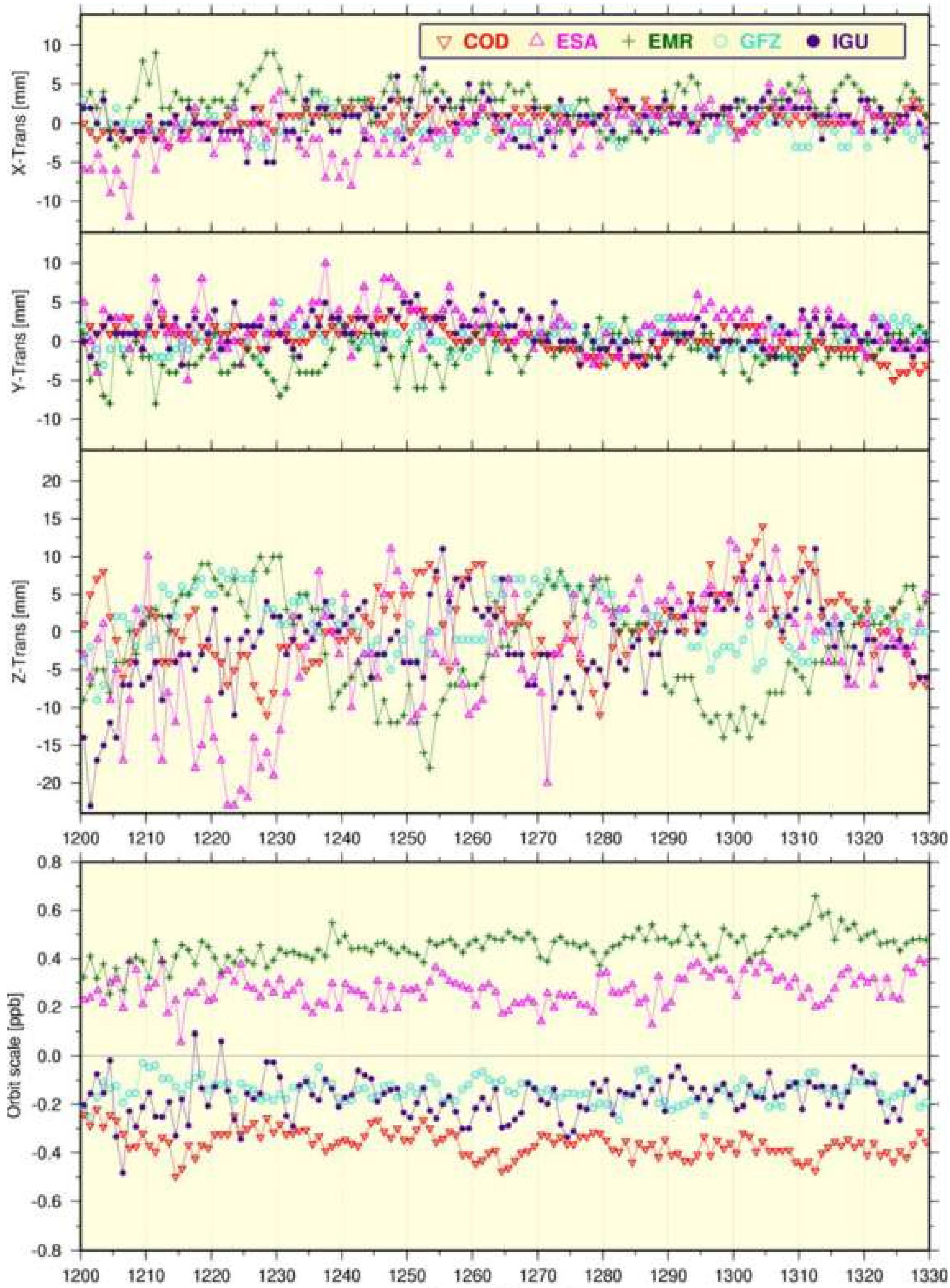


Figure 8: Weekly mean translation parameters and scale of the AC Rapid and IGS Ultra Rapid (IGU) orbits with respect to the IGS Rapid orbits (for ACs: COD, ESA, EMR, GFZ)

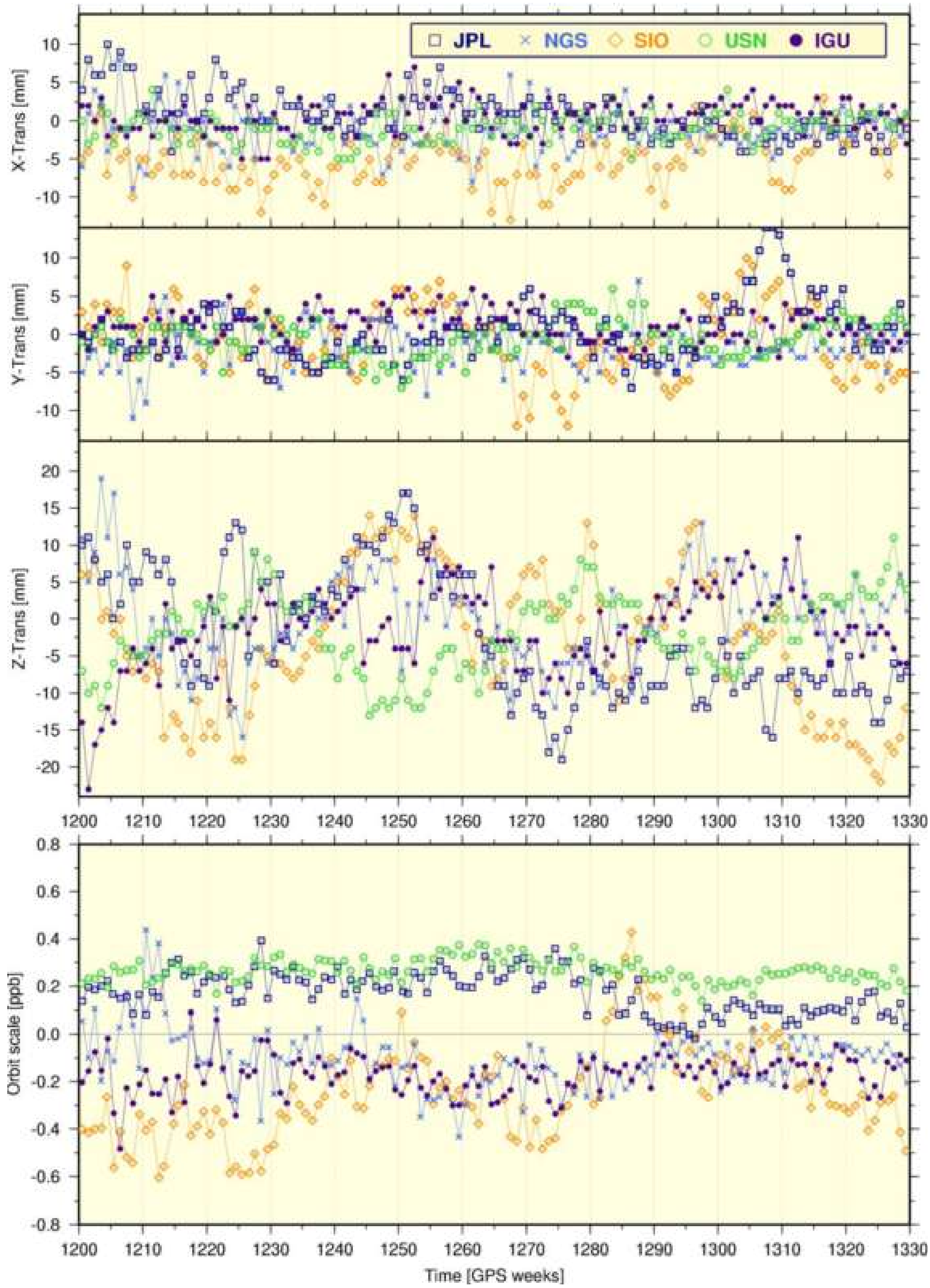


Figure 9: Weekly mean translation parameters and scale of the AC Rapid and IGS Ultra Rapid (IGU) orbits with respect to the IGS Rapid orbits (for ACs: JPL, NGS, SIO, USN)

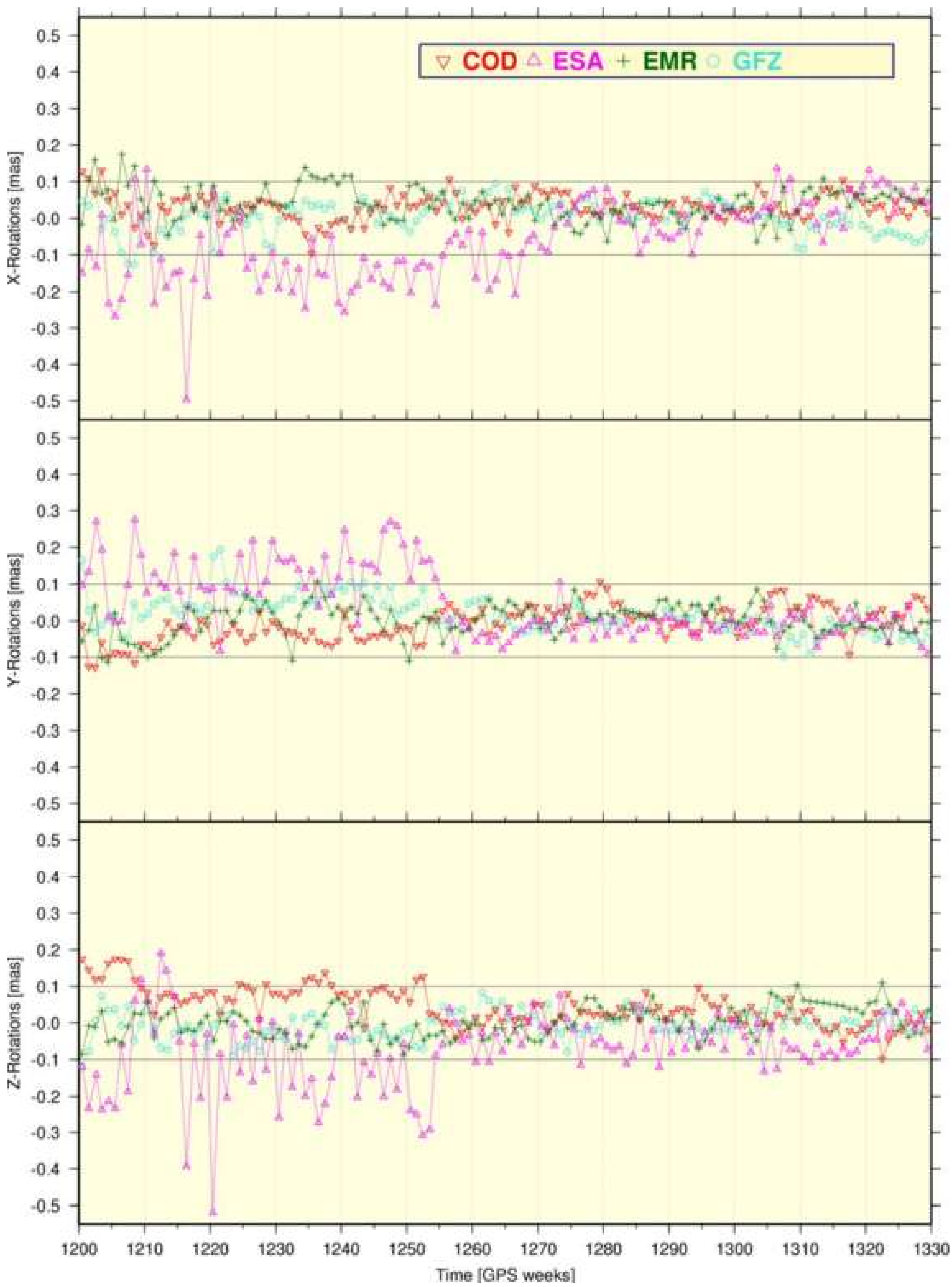


Figure 10: Weekly mean rotation parameters of the AC Rapid orbits with respect to the IGS Rapid orbits (for ACs: COD, ESA, EMR, GFZ).

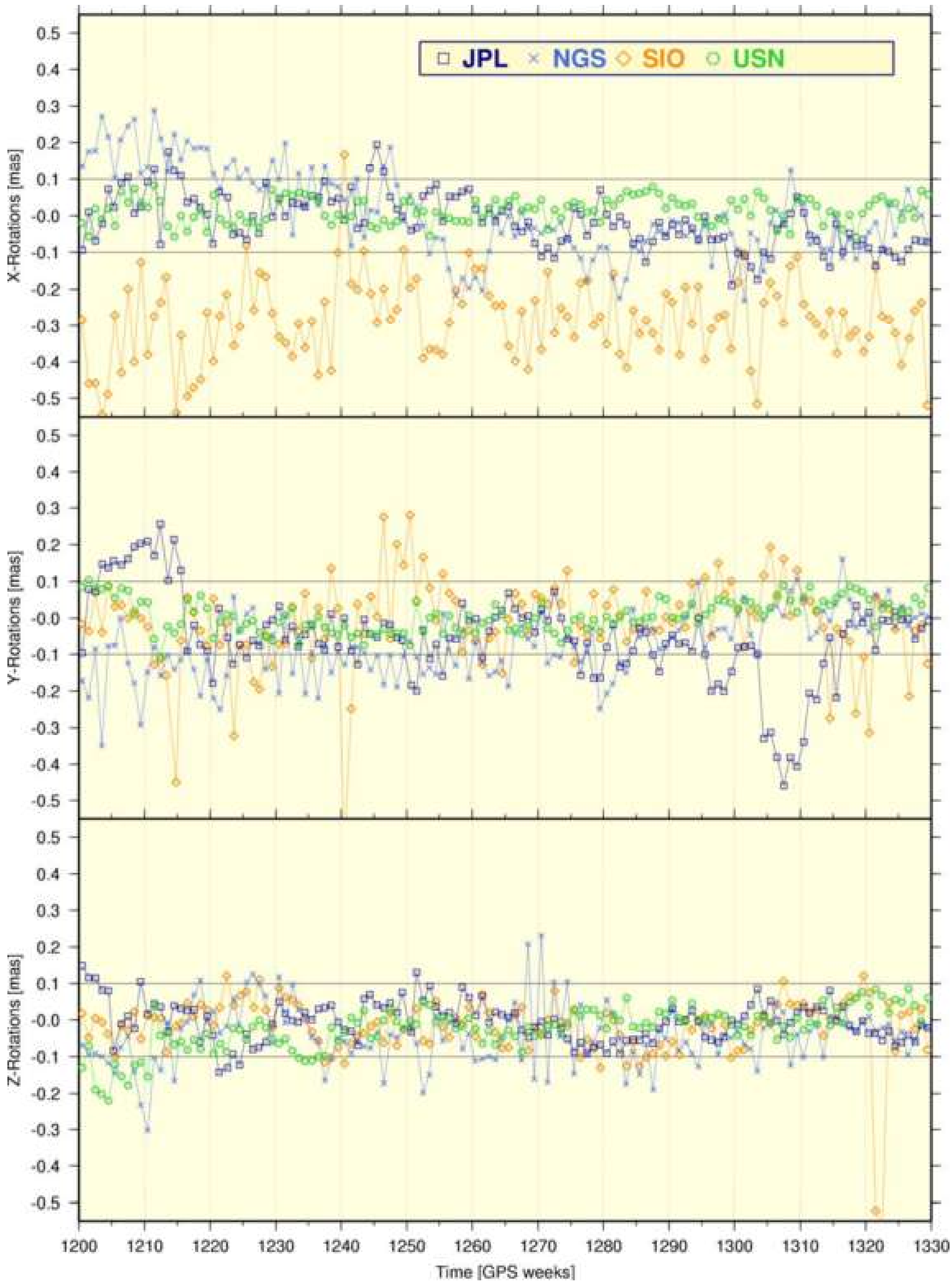


Figure 11: Weekly mean rotation parameters of the AC Rapid orbits with respect to the IGS Rapid orbits (for ACs: JPL, NGS, SIO, USN).

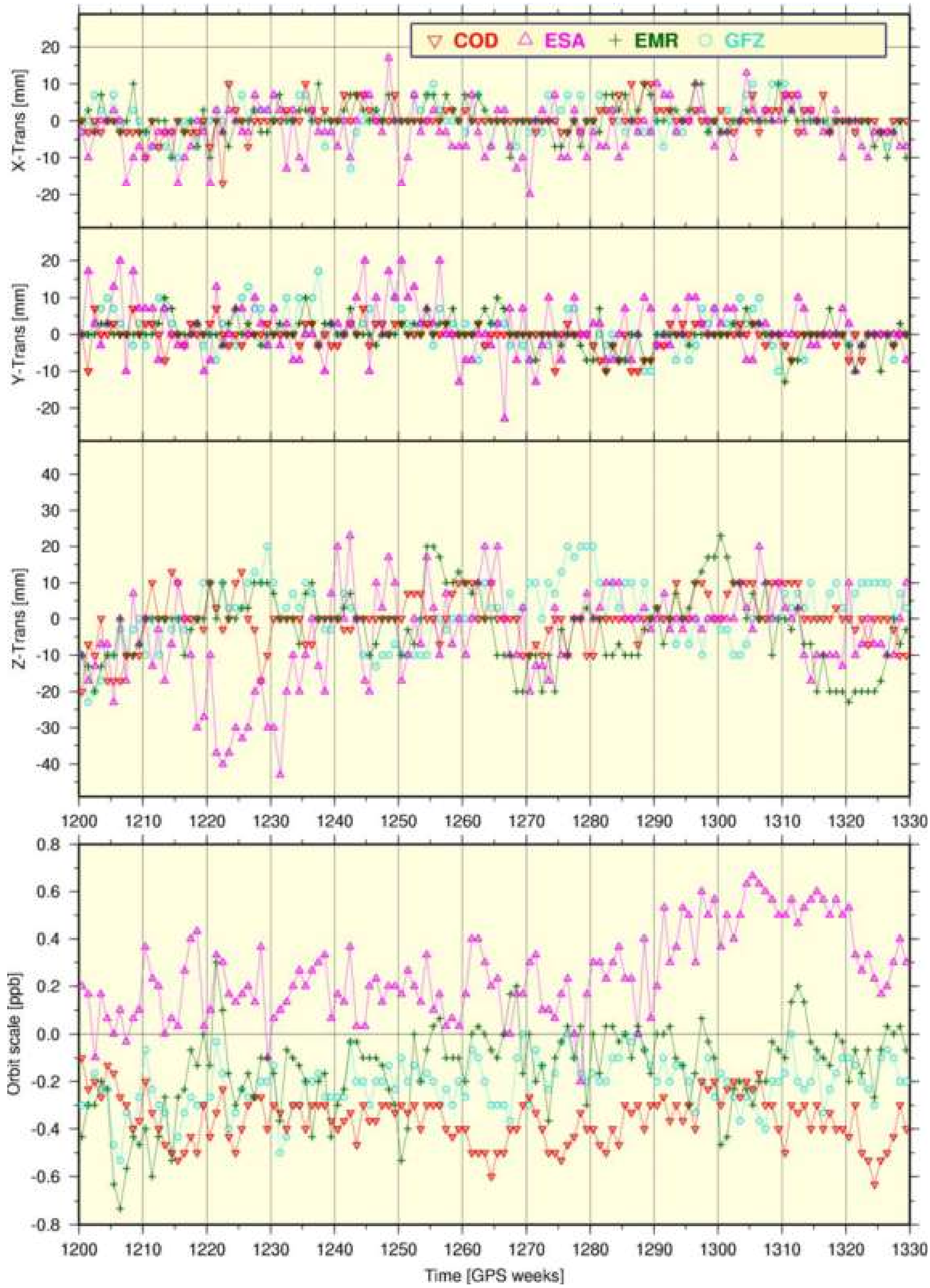


Figure 12 : Weekly mean translation parameters and scale of the AC Ultra Rapid orbits with respect to the IGS Rapid orbits (for ACs: COD, ESA, EMR, GFZ).

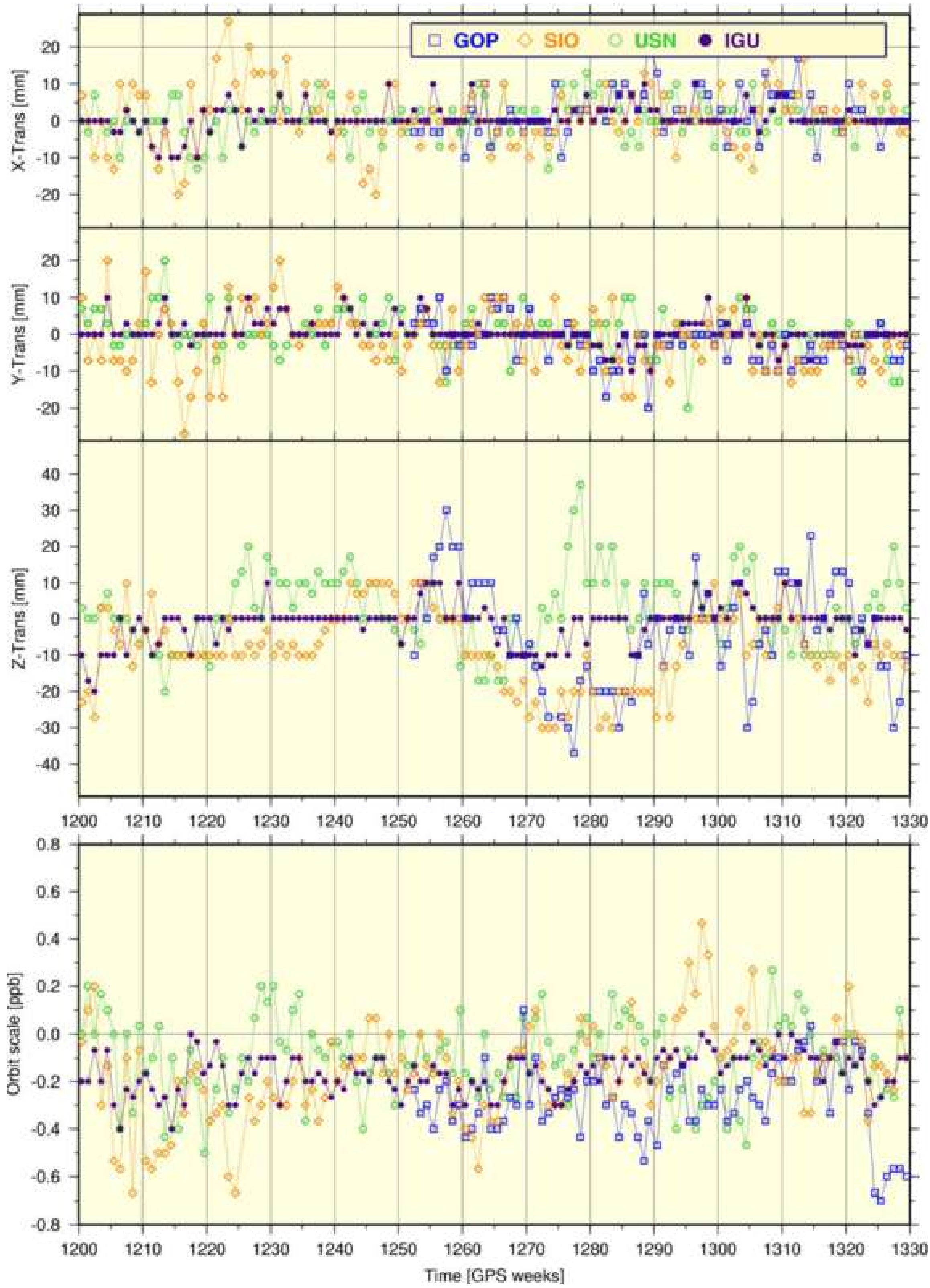


Figure 13: Weekly mean translation parameters and scale of the AC Ultra Rapid orbits with respect to the IGS Rapid orbits (for ACs: GOP, SIO, USN).

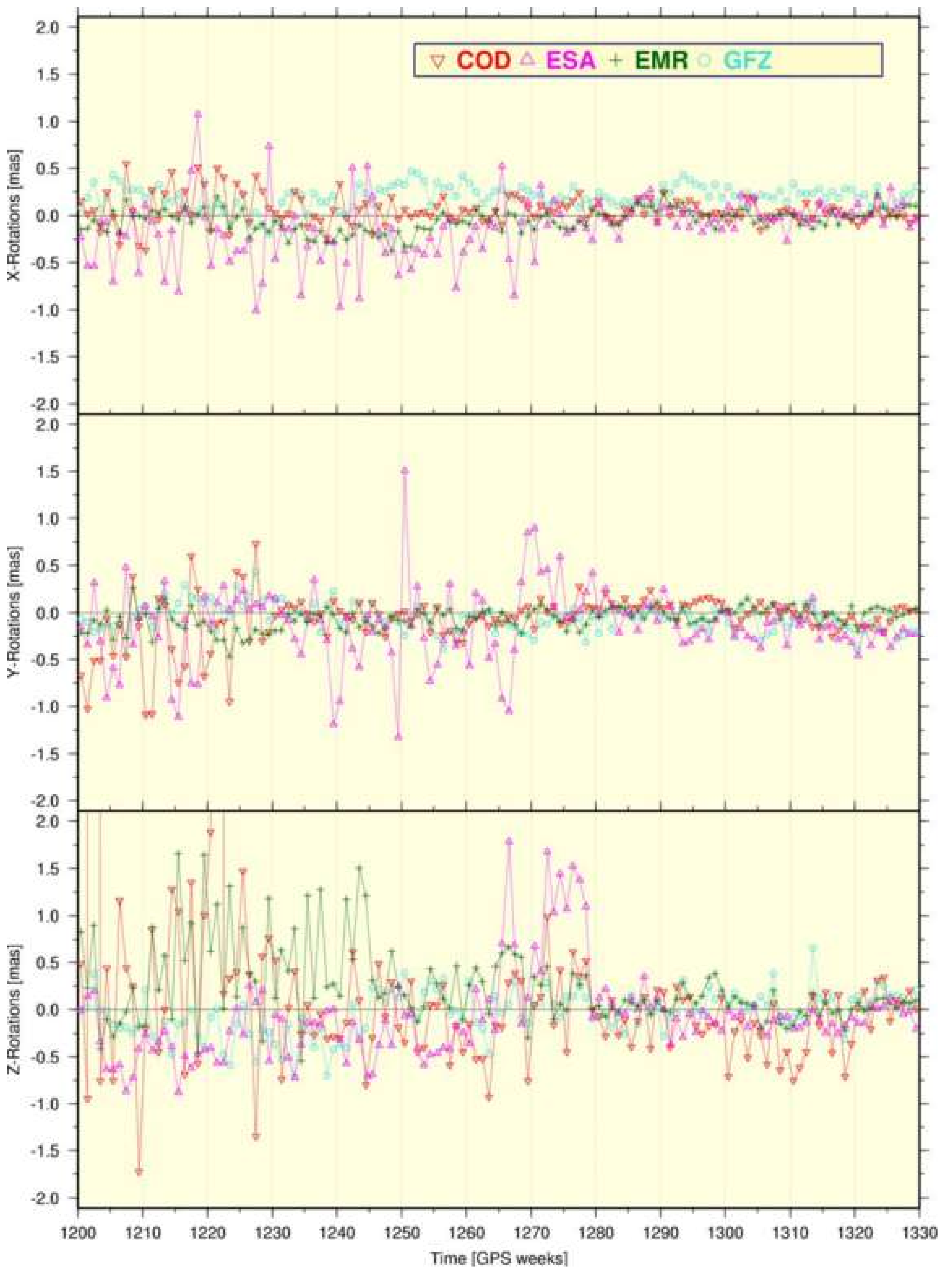


Figure 14: Weekly mean rotation parameters of the AC Ultra Rapid orbits with respect to the IGS Rapid orbits (for ACs: COD, ESA, EMR,GFZ).

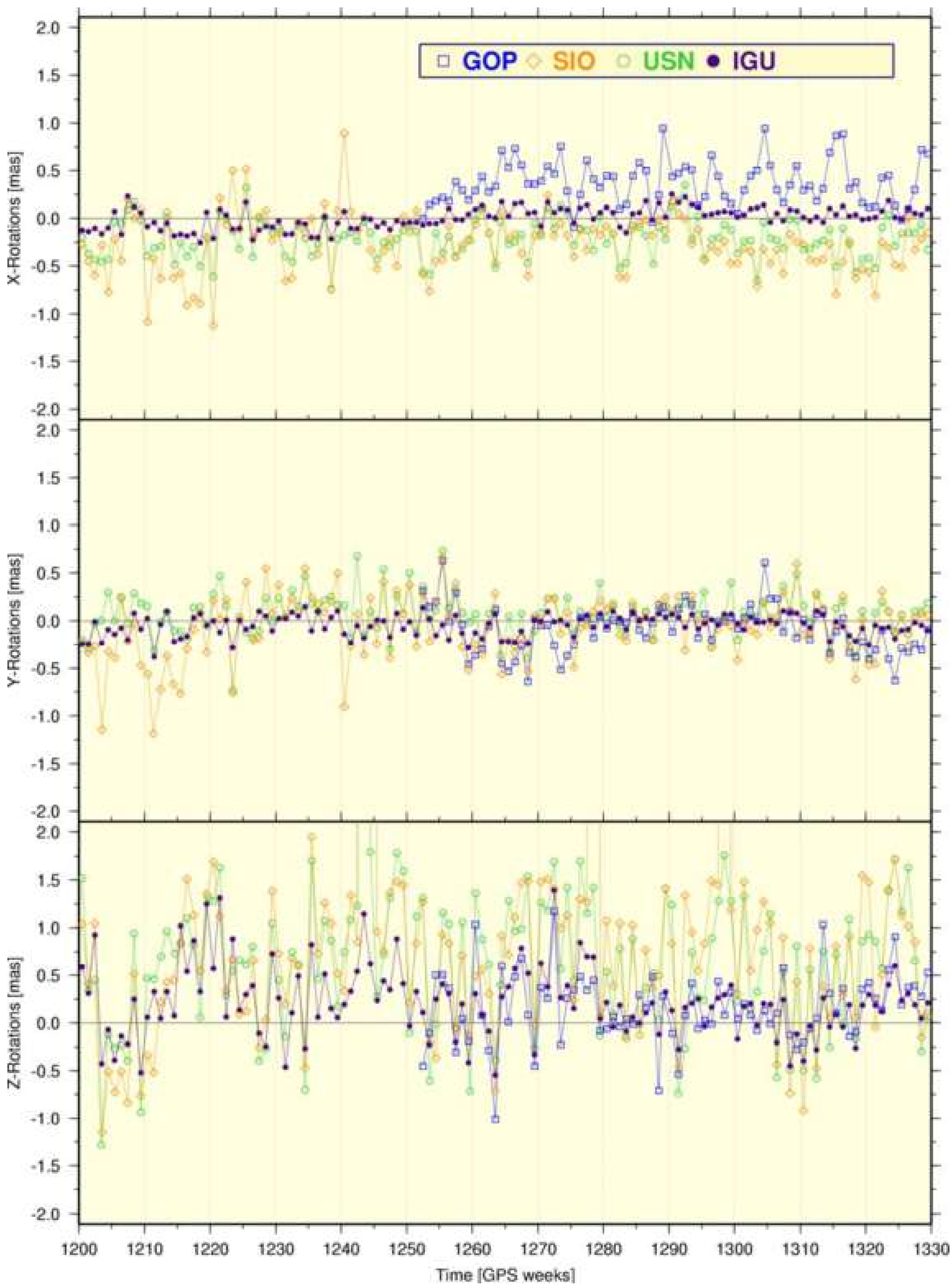


Figure 15: Weekly mean rotation parameters of the AC Ultra Rapid orbits with respect to the IGS Rapid orbits (for ACs: GOP, SIO, USN).

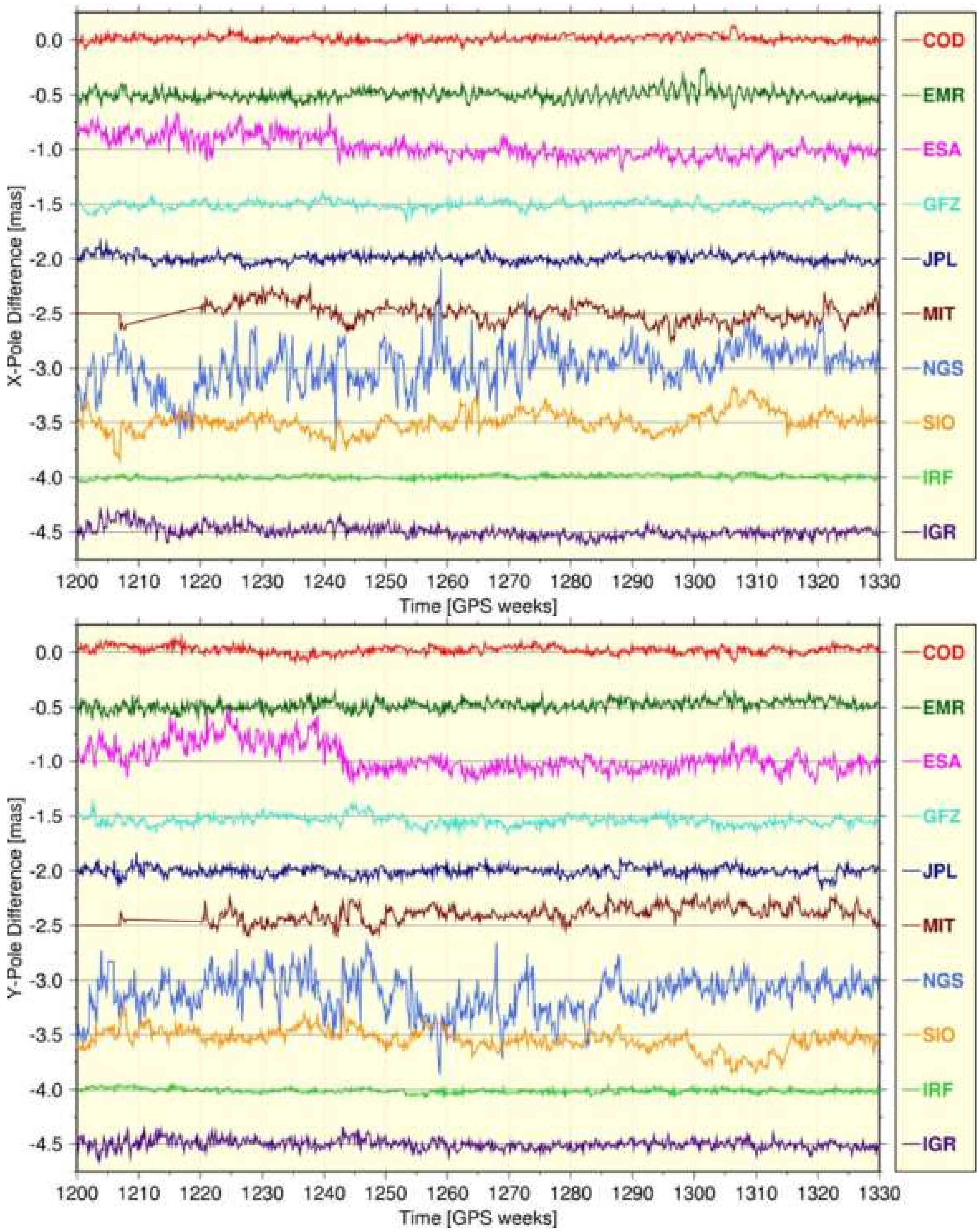


Figure 16: Daily differences of the AC Final Pole, the IGS Rapid (IGR) Pole and the IRF Pole (Pole from SINEX combination) with respect to IGS Final Pole (unweighted combination of AC erp-files).
(Note: The scale of the ordinate axis is different from the Rapid and Ultra Rapid plots!)

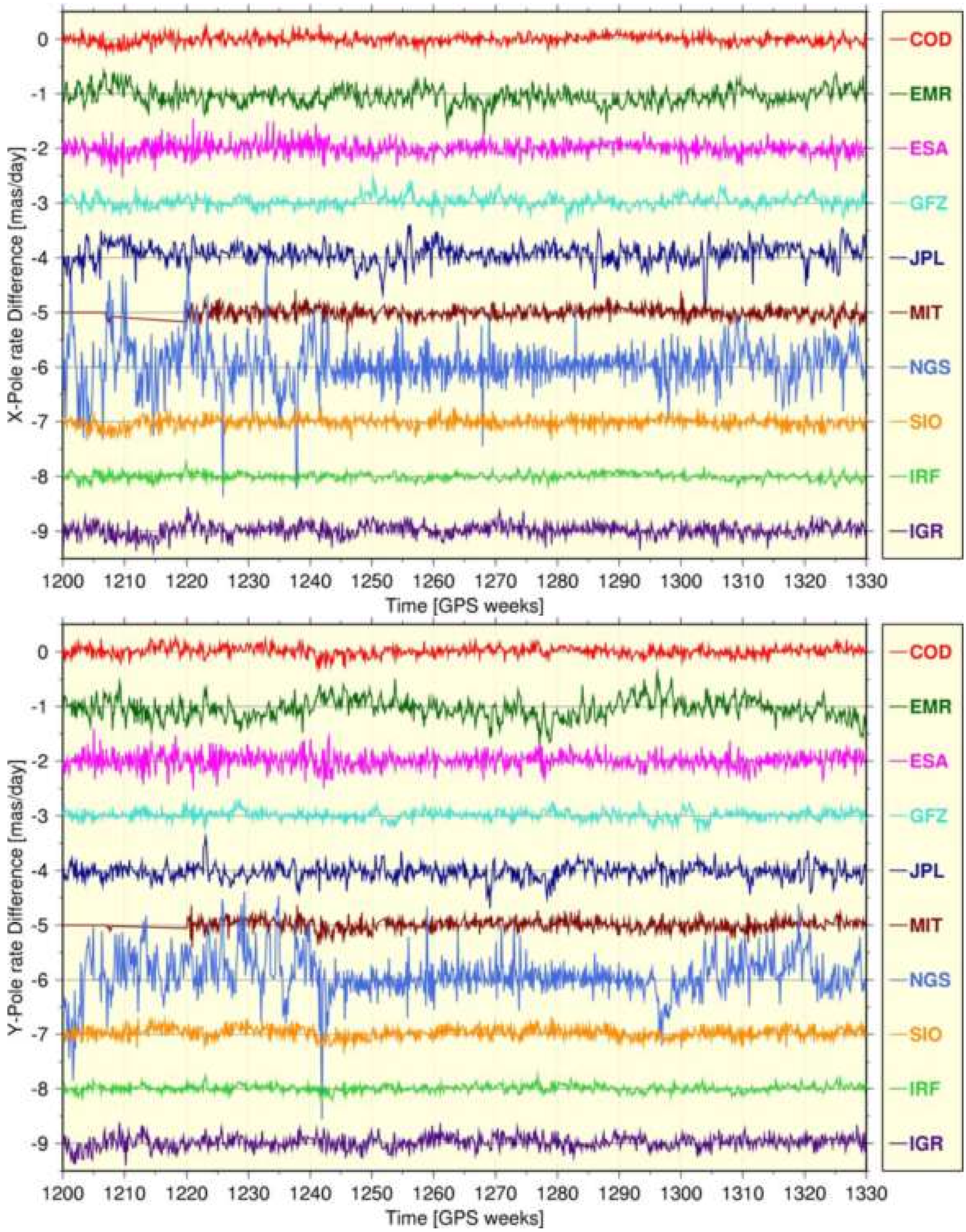


Figure 17:Daily differences of the AC Final Pole-rate, the IGS Rapid (IGR) Pole-rate and the IRF Pole-rate (Pole from SINEX combination) with respect to IGS Final Pole-rate (unweighted combination of AC erp-files).

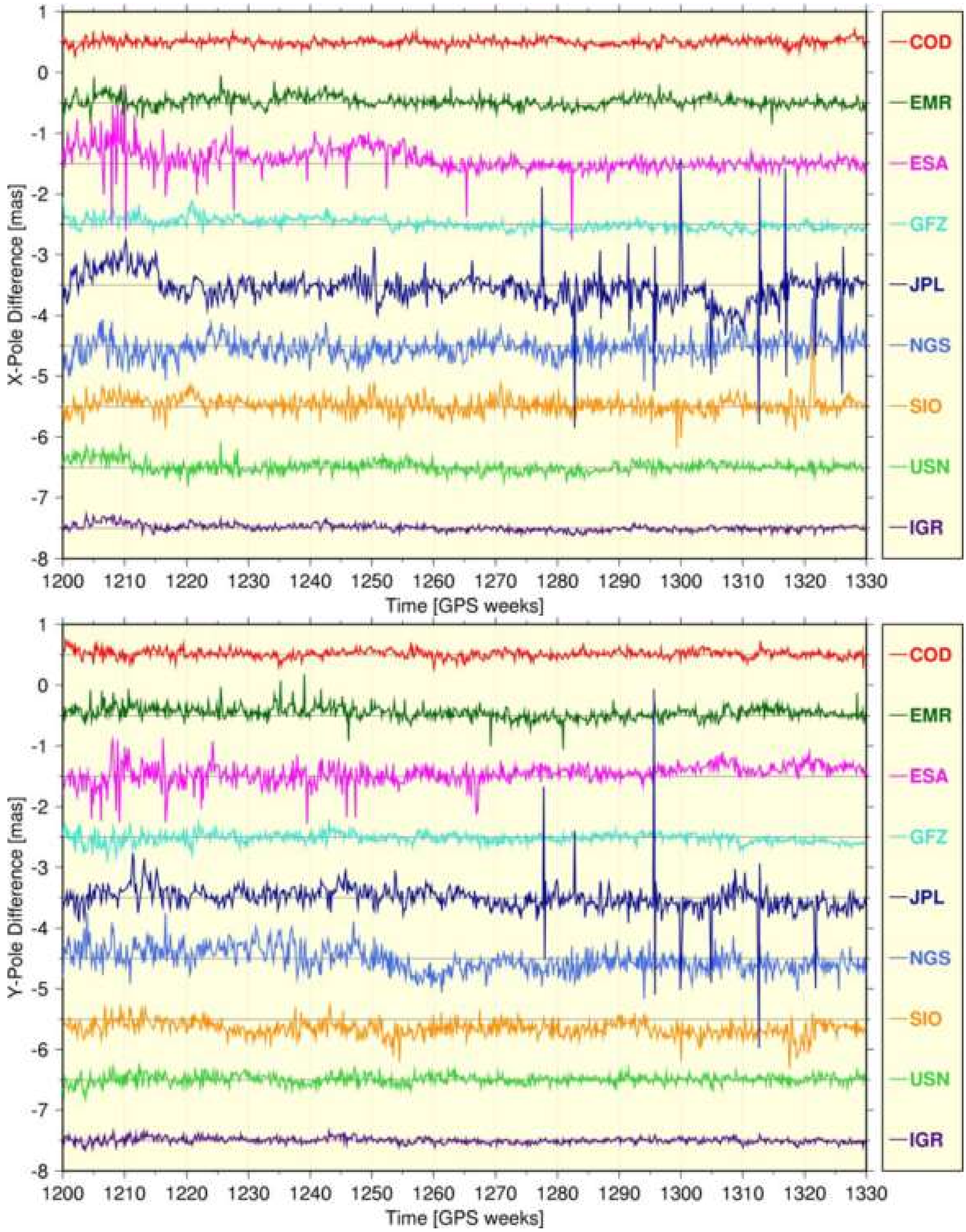


Figure 18:Daily differences of the AC Rapid Pole and the IGS Rapid (IGR) Pole with respect to IGS Final Pole (unweighted combination of AC erp-files).

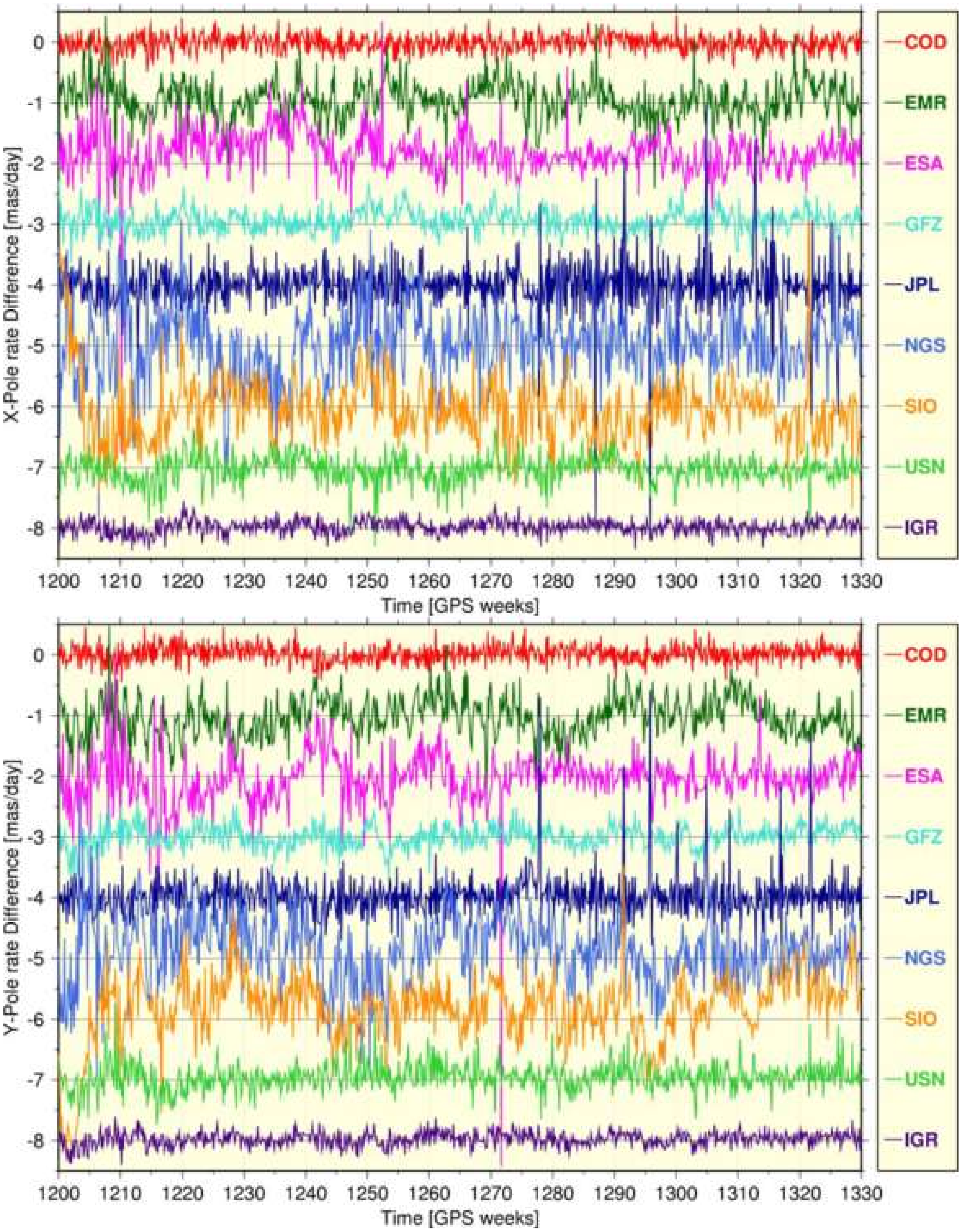
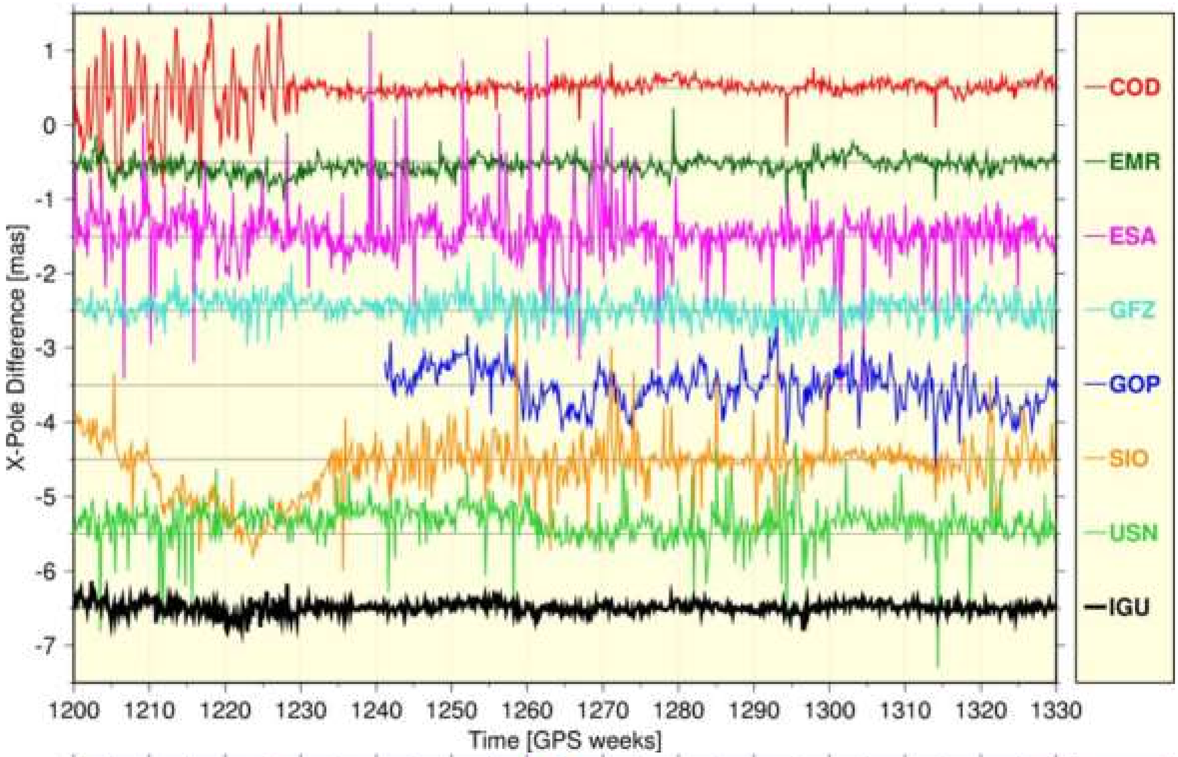


Figure 19: Daily differences of the AC Rapid Pole-rate and the IGS Rapid (IGR) Pole-rate with respect to IGS Final Pole-rate (unweighted combination of AC erp-files).



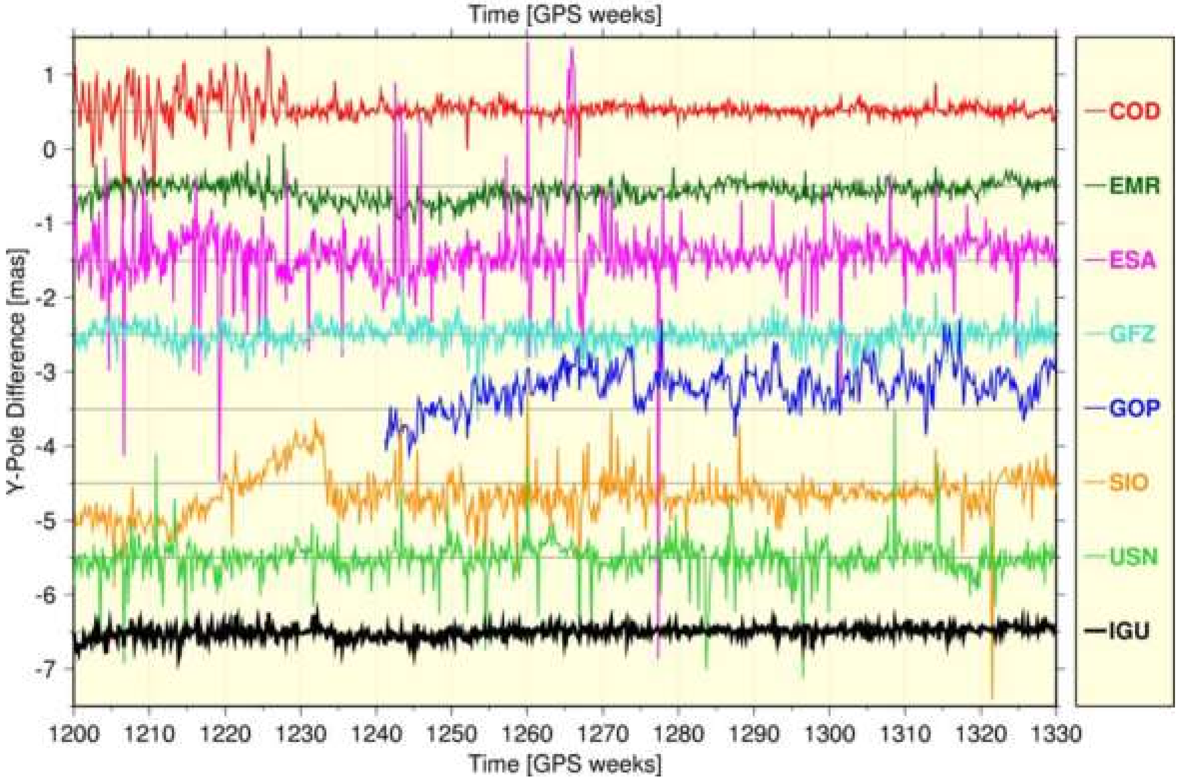


Figure 20: Daily differences of the AC Ultra Rapid Pole and the IGS Ultra Rapid (IGU) Pole with respect to IGS Rapid Pole (unweighted combination of AC erp-files).

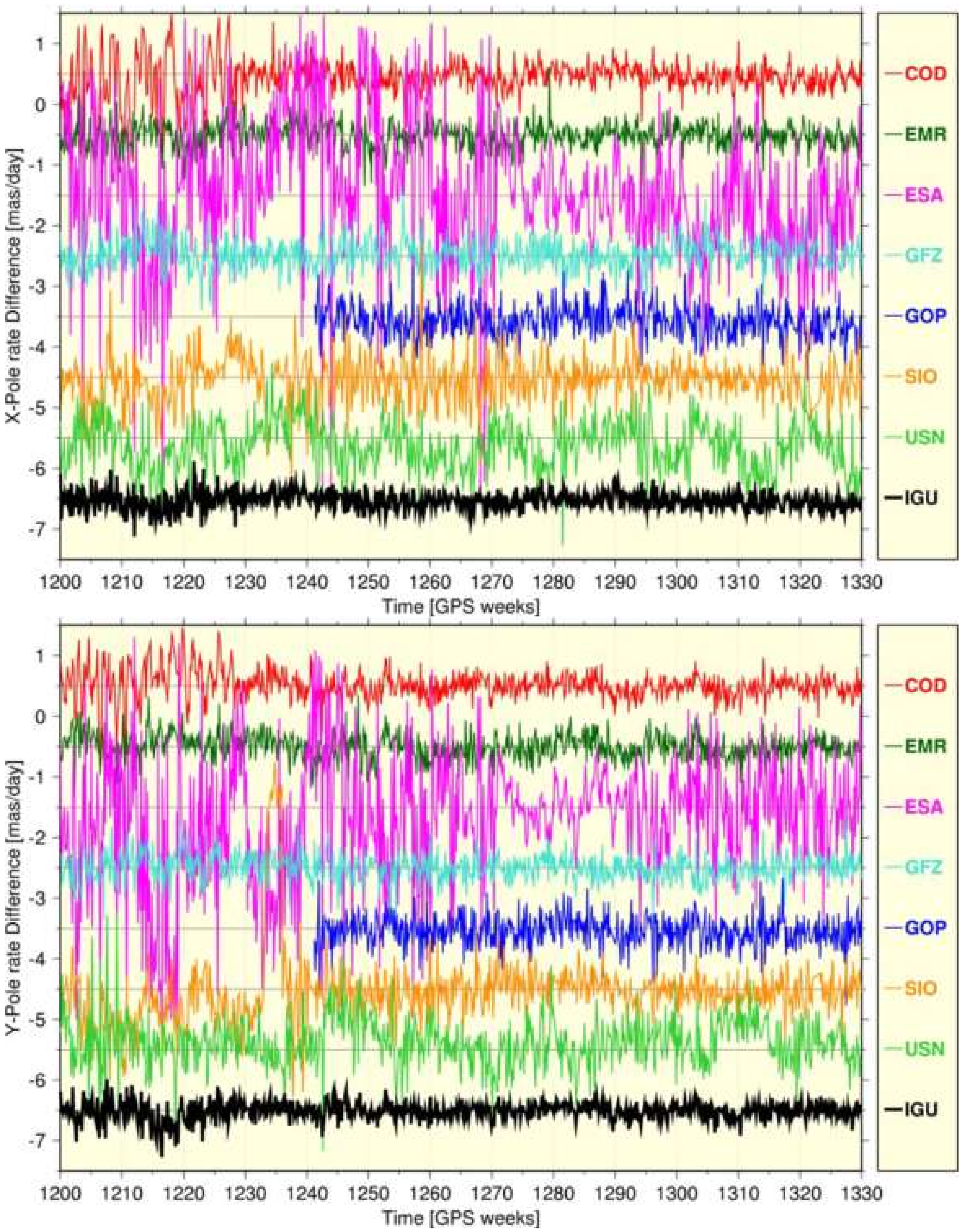


Figure 21:Daily differences of the AC Ultra Rapid Pole-rate and the IGS Ultra Rapid (IGU) Pole-rate with respect to IGS Rapid Pole-rate (unweighted combination of AC erp-files).

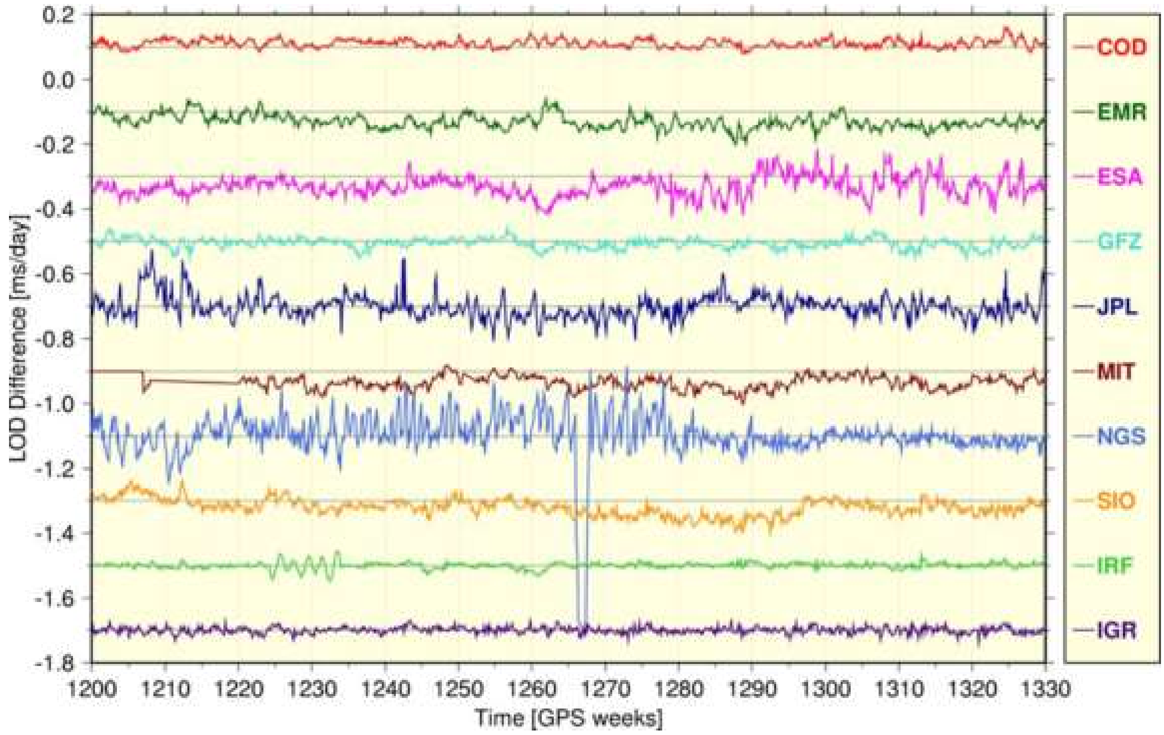


Figure 22: Daily differences of the AC Final LOD and IGS Rapid (IGR) LOD with respect to IGS Final LOD (unweighted combination of AC erp-files).

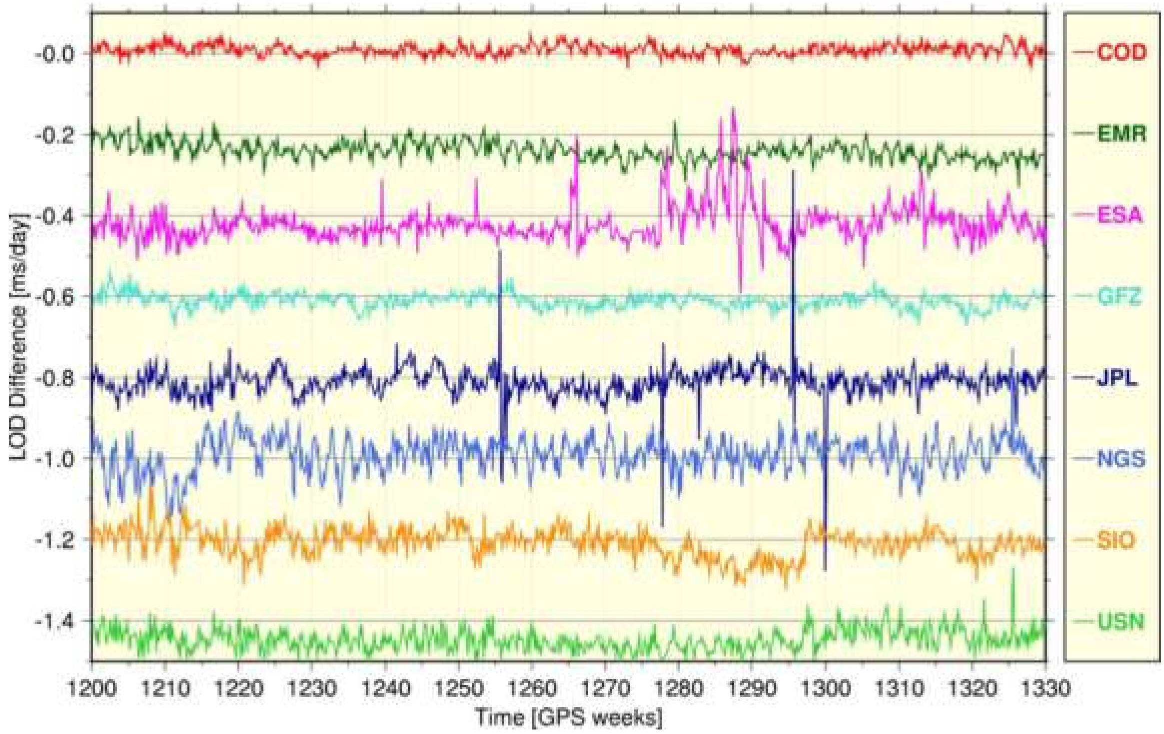


Figure 23: Daily differences of AC Rapid LOD with respect to IGS Final LOD (unweighted combination of AC erp-files).

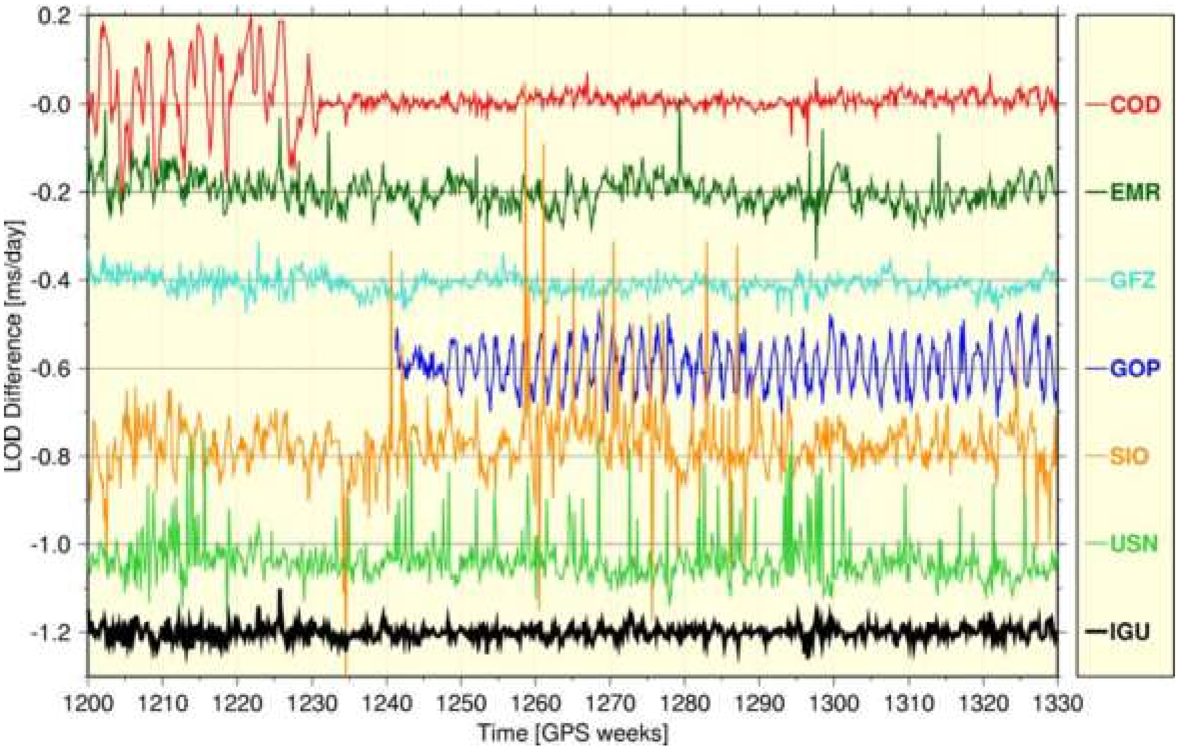


Figure 24: Daily differences of the AC Ultra Rapid LOD, IGS Ultra Rapid (IGU) LOD with respect to IGS Rapid LOD (unweighted combination of AC erp-files).

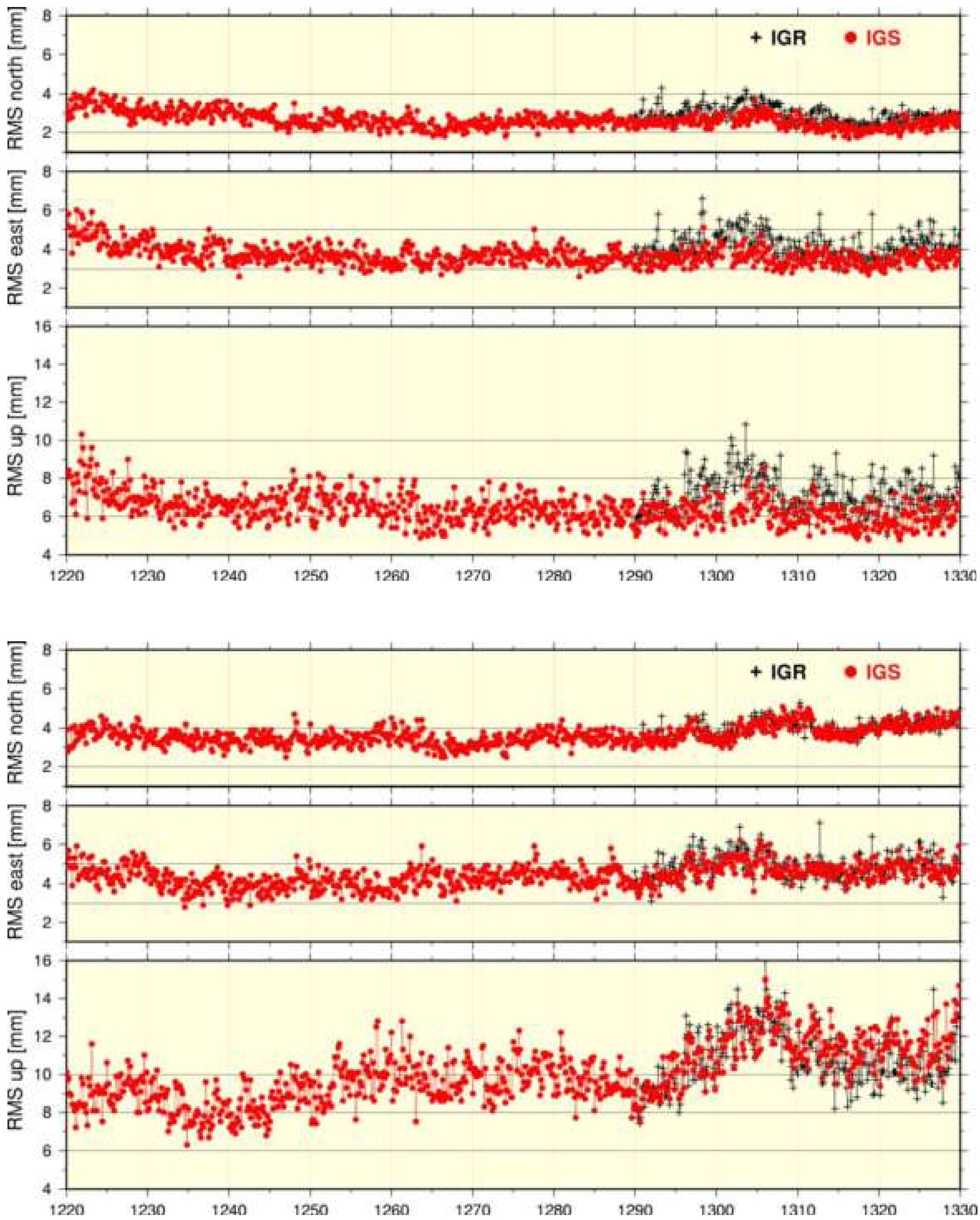


Figure 25: Helmert transformation results (RMS) between combined weekly SINEX solutions (top)/IGb00 (bottom) and PPP solutions using combined IGS Final (IGS) and Rapid (IGR) orbits and clocks. The PPP is performed for all stations defining the reference frame IGb00.

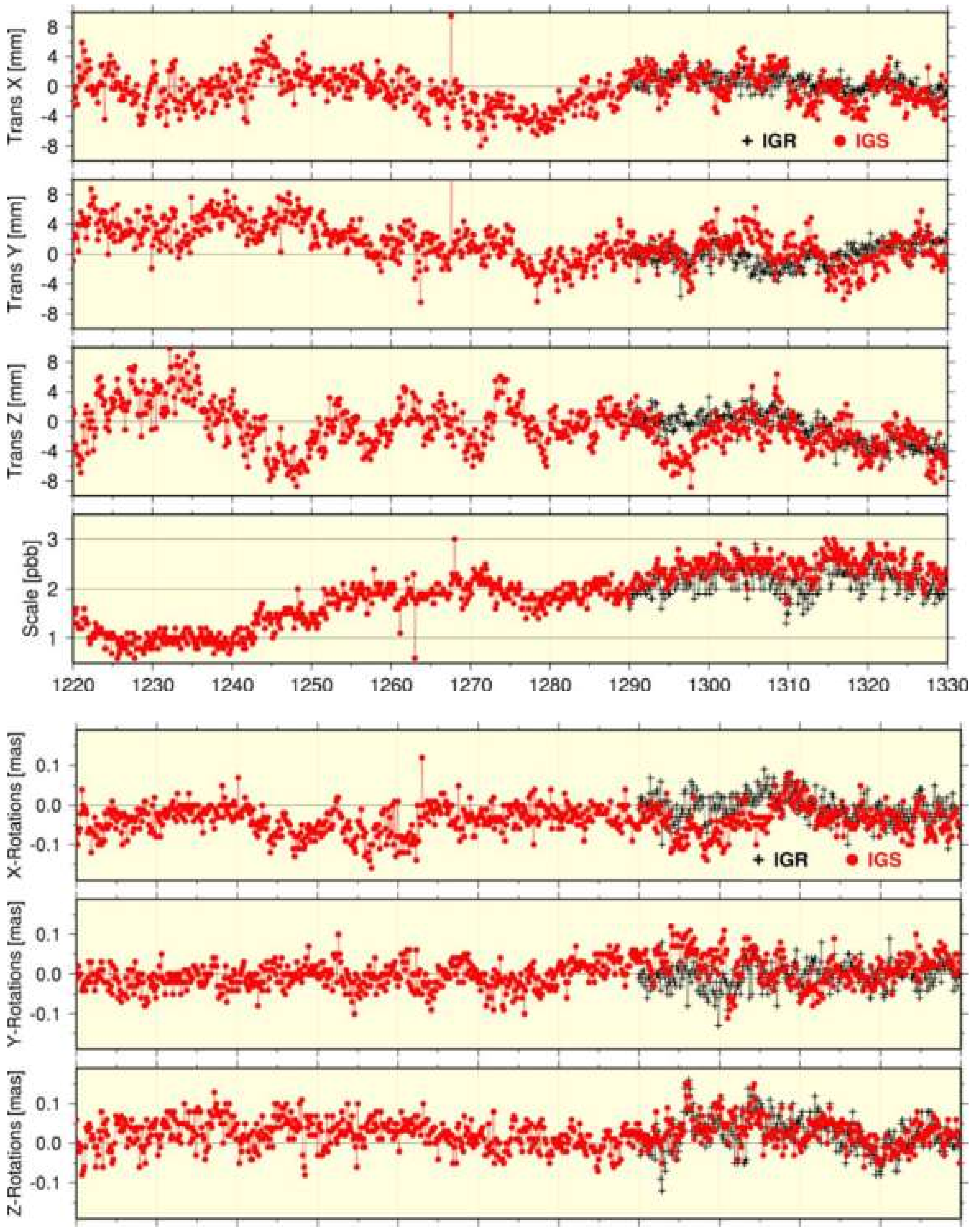


Figure 26: Helmert transformation results (translation and scale; rotation) between IGb00 and PPP solutions using combined IGS Final (IGS) and Rapid (IGR) orbits and clocks. The PPP is performed for all stations defining the reference frame IGb00.

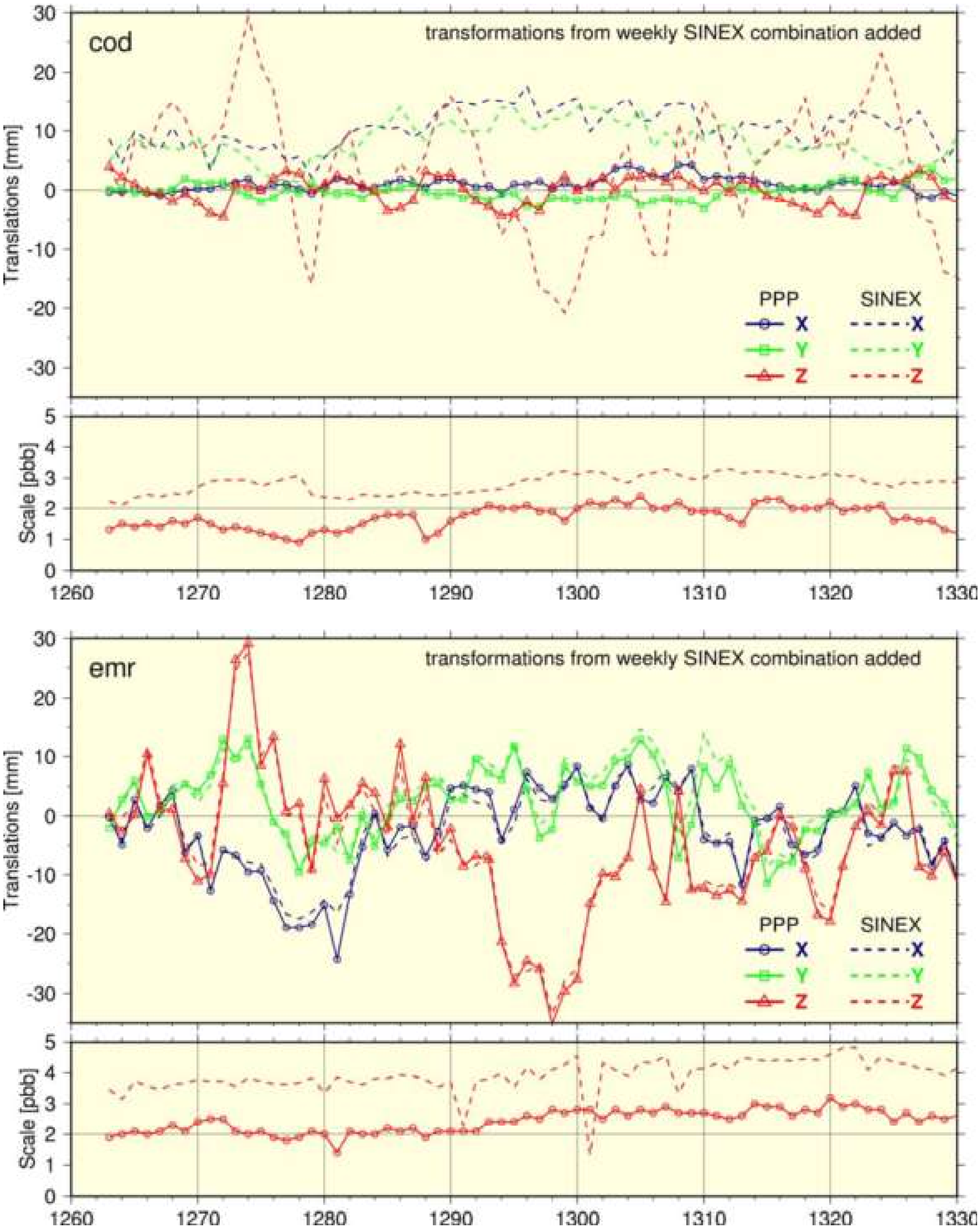


Figure 27: Helmert transformation results (translation and scale) between IGb00 and PPP solutions using the AC Final orbits and clocks (examples for COD and EMR). The PPP is performed for all stations defining the reference frame IGb00. For comparison the AC's transformation results within the SINEX combination are added.

MIT IGS Analysis Center Report for 2003-2004

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Introduction

The MIT IGS analysis center is focused primarily on global clock solutions. In order to ensure that the clock estimates are consistent with orbits of the satellites, we submit a full set of IGS final products each week. For the analysis we use the GAMIT/GLOBK package. The strategy in the analysis is to form networks of 40 stations with 4 such networks processed each day using the GAMIT package. The four networks are merged each day with GLOBK into a single 148-station network with a common orbit parameterization. The types of clocks at the GPS stations define the base networks. One network starts with the time service clock stations and the others are those remaining stations with hydrogen maser, cesium and rubidium clocks. The number of stations in each base network is less than 40 and the remaining stations in each network are selected based on available data at the time of the analysis (normally 5 days behind real-time). Four stations, two from each polar region and 2 from the equatorial region, are used to tie the networks together. The networks share four common stations although the specific stations can vary day-to-day depending on available data. Between 2003-2004, the dynamic addition of sites has lead to the inclusion of 188 sites with at least 25 weeks of data and over 200 sites used at least 8 times. The median root-mean-square (RMS) scatters of the position estimates from the weekly combinations of the 188 sites about the best fit linear trends are 1.8 mm, North, 2.1 mm East and 5.8 mm, Up. The MIT orbits match the final IGS orbits with a typical RMS difference of 3 cm. However for a group of satellites, every 6 months for periods of few weeks, the MIT orbits deviate greatly from the IGS orbits. Our analyses with absolute phase center models have shown that these deviations arise from the combined effects of our use of the IGS standard model (with satellite independent phase center locations within each satellite block type) and geometry dependent high correlations between orbit parameters and radiation parameter estimates. The deviations seen in our routine processing are not seen when satellite dependent phase center models are used.

MIT Analysis Products and Methods

On a weekly basis, MIT generates final clock, orbit, earth orientation parameters (EOPS), and SINEX products named mitWWWWN.clk, mitWWWWN.sp3, mitWWWW7.erp, and mitWWWW7.snx, where WWWW is GPS week number and N is day of week. In addition a summary file mitWWWW7.sum is generated that contains station information and our assessment of orbit quality. The MIT weekly products are generated from 9 days of data with the last day of the previous week and the first day of the next week included so that the rate of change EOP parameters on the first and last day of the week have data on both sides. This procedure results in all days of the week having similar standard deviations for the EOPS. The models used in the MIT analysis are given in http://igscb.jpl.nasa.gov/igscb/center/analysis/mit.acn.

The orbit parameterization and estimation used in the MIT analysis is based on the Berne models described in Beutler *et al*. [1994] and Springer *et al.* [1998]. The estimated parameters in this model are satellite initial position and velocity (IC) at a specified time plus nine radiation-pressure terms made up of constant and sine and cosine once-per-rev terms| for the direct radiation effect, Y-axis bias, and B-axis acceleration (the B-axis completes the right handed triad with the direct and Y axes). The ICs are independently estimated each day from 24 hours of data. The radiation parameters are treated as random walk parameters with process noise values based on variations of the independent daily estimates of the parameter values. For many satellites and radiation parameters the day-to-day variations are small enough (compared to the standard deviations of the estimates) that zero process noise is used in the estimation, which leads to a single constant estimate of the radiation parameter for the week.

This parameterization of the radiation effects at times is poorly determined depending on the geometry of the satellite orbit plane and the location of the Sun and we have observed that when some of the radiation parameters are poorly determined (particularly the B-axis parameter) the match of the MIT orbits to the IGS orbits is very poor. However, all satellites in a given orbit plane have similar standards deviations for the radiation parameters and yet not all satellites disagree with the IGS orbits during the poorly determined periods. As an example, Figure 1 shows estimates of the B-axis radiation parameter as a fraction of the direct radiation force for the years 2003 ad 2004. The dramatic increases in the B-axis parameter estimate every 6-months is clear. At the times of the peaks, the MIT orbit estimates for PRN28 deviated from the IGS estimates with RMS differences of up to 30 cm (ten times higher than normal).

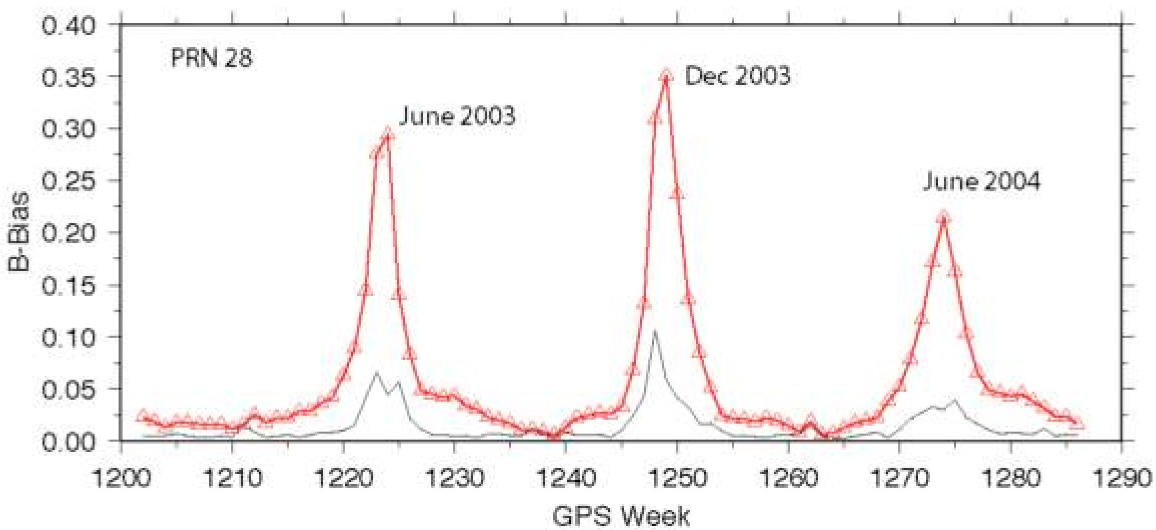

Figure 1: Estimates of the B-axis radiation parameter for PRN 28. The red line is the estimate and the black line is the weekly RMS scatter of the estimate. Value is fraction of direct radiation force.

Other, but not all, satellites showed similar behavior. We did not understand this behavior until we started running parallel absolute and relative phase center models. When the new IGS absolute phase center models are used, the problem with anomalous B-axis radiation parameter estimates and the mismatch of the MIT and IGS orbits is removed.

Satellite phase center model effects

In May of 2005, the IGS adopted an absolute phase center model to be tested by the IGS analysis centers. Since the beginning of June 2005, five of the eight IGS analysis centers (EMR, GFZ, MIT, NGS, SIO) have been submitting parallel processing using the standard relative phase center model and the new absolute phase center models. The new phase center model differs from the current relative model in several important ways. In the relative model, the satellite phase center was modeled as a point source located at specific location relative to the center of mass of the spacecraft. The location of the phase center was dependent only on the satellite block, i.e., there was one location for all Block IIA satellites, and another location for all Block IIR satellites. Of the 29 satellites currently available, 12 are Block IIR and the rest are Block IIA. In the analyses to determine the new satellite phase center models, it was realized that an antenna redesign in the Block IIR satellites changed the phase center variations for these new satellites. The Block IIR satellites are now divided into Block IIR-A (the original group of 8 satellites) and the new group Block IIR-B (currently 4 in orbit). The newest satellite launched (Launched September 23, 2005) is classified as a Block IIR-M and seems to have a different phase center pattern to the other Block IIR satellites, although it is close to the Block IIR-B pattern. The other major change with the new phase center model is that the locations of the phase centers appear to be satellite specific with satellites within the same class showing differences in the Z-direction (direction towards the Earth) of up to 50 cm. These differences have had a major impact on MIT orbit determinations when the (fixed phase center) relative models are used (current practice). We report here on the results obtained from the MIT parallel runs.

We noted above the anomalous orbit modeling error that resulted in large values for some radiation parameter estimates (Figure1) and the poor agreement between the MIT and IGS orbits. We now know this anomaly occurs because of the error in the phase center location of specific satellites mapping into the orbit determination. The anomalies noted with the relative phase models are not present when the new absolute phase center models are used. Figure 2 shows examples of the improvement in the match of the MIT orbits to the IGS orbits when the absolute phase centers are used. Dramatic improvements can be seen for PRN 28, which had just peaked in its error with the relative model when the absolute phase center parallel test runs started, and for PRN 03 whose relative model error peaked in mid-July 2005. PRN 11 also shows degradation in the relative model in late August 2005. For PRN 28 and PRN 03, the RMS differences between MIT and IGS orbits reach 26 to 28 cm with the relative model and reduce to 2 to 3 cm with the absolute model. For PRN 11 the improvement is from 14 cm to 2 cm. The orbits determined with the absolute phase center model are being compared here to the original IGS orbits. There have been limited combinations of the orbits from the 5 centers to generate absolute model IGS orbits and in the MIT absolute orbits compare to this combination with an RMS difference of 2 cm. The IGS ACC site ftp://ftp.gfz-potsdam.de/pub/igsacc/product/final_parallel/ has results for preliminary comparisons of the new absolute phase center orbits.

The different behaviors of these satellites can be understood when the estimates of the phase center locations of the different satellites is considered. The IGS absolute phase center model have Z-offsets in the phase satellite phase center locations that are PRN dependent. Both PRN 28 and PRN 03 have Z-locations that deviate about 30 cm from the nominal values for the block type. PRN 11 also deviates from the average for its block type (IIR-A) but not by as much as PRN 28. These results clearly show the sensitivity to parameters such as phase center locations. The improvement in orbit quality seen with the absolute phase center model also indicates the absolute phase center model is of high quality. We are left in a dilemma for the remaining time of using relative phase center models: We can constrain the radiation parameter estimates to match the IGS orbits or we could introduce satellite dependent phase center locations (same relative offsets as the absolute model) which is the correct approach but we would then not be adhering to IGS standards. Since this problem is removed when the absolute phase center models are adopted early in 2006, we will not change our current procedures and be aware that the periodic degradation of our orbit match to IGS orbits is due the errors in the phase center locations.

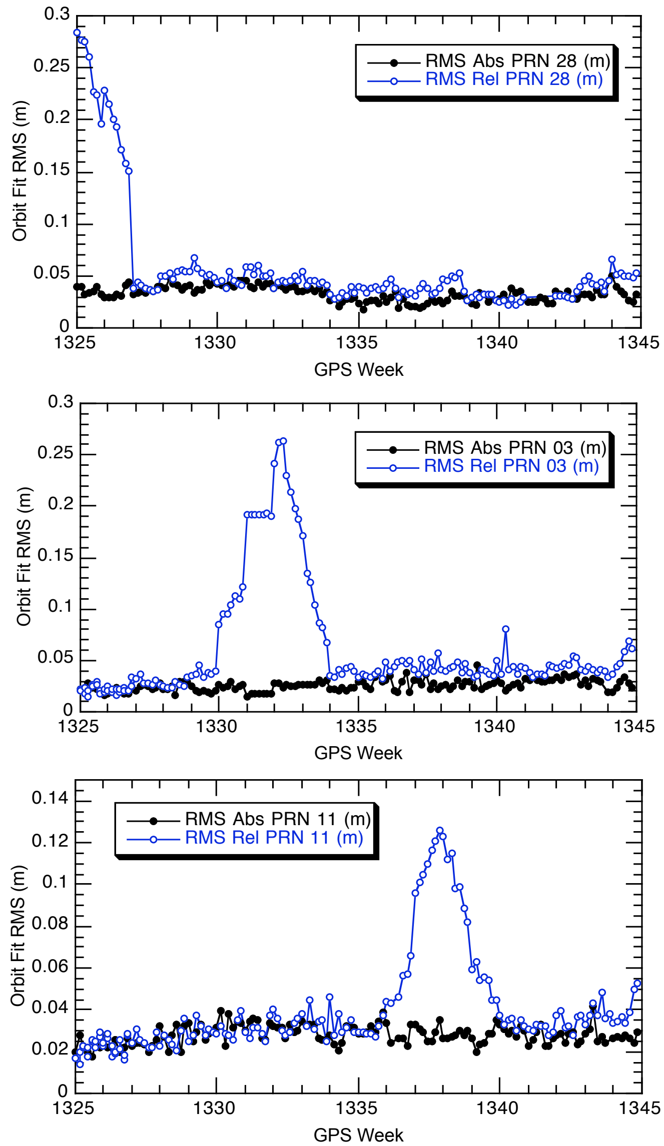

Figure 2: Comparison of the RMS difference between MIT and IGS determined orbits for three satellites. The blue results are for the relative phase center model with the same phase center location for each satellite block; the black results are for the absolute phase center model with satellite dependent phase center locations. The time axis is GPS weeks with Week 1325 starting May 29, 2005 and week 1344 ending October 15, 2005.

References

Beutler, G., E. Brockmann, W. Gurtner, U. Hugentobler, L. Mervart, and M. Rothacher, Extended Orbit Modeling Techniques at the CODE Processing Center of the International GPS Service for Geodynamics (IGS): Theory and Initial Results, Manuscripta Geodaetica, 19, 367-386, 1994.

Springer, T. A., G. Beutler, and M. Rothacher, A new solar radiation pressure model for the GPS satellites, IGS Analysis Center Workshop, Darmstadt, 9-11 February 1998.

CODE IGS Analysis Center Technical Report 2003/2004

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Introduction

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following four institutions:

- the Federal Office of Topography (swisstopo), Wabern, Switzerland,
- the Federal Agency of Cartography and Geodesy (BKG), Frankfurt, Germany,
- the Institut Géographique National (IGN), Paris, France, and
- the Astronomical Institute of the University of Berne (AIUB), Berne, Switzerland.

CODE is located at the AIUB. All solutions and results are produced with the latest development version of the Bernese GPS Software [Hugentobler et al., 2005].

This report covers the time period from January 2003 through December 2004. It focuses on major changes taken place in the routine processing during this period and shows new developments and products generated at CODE. The processing strategies used in previous years are described in [Hugentobler et al, 2002] and earlier CODE annual reports.

A highlight was the IGS Workshop and Symposium 2004 that was hosted at the Bern University from March 1 to 5, 2004, celebrating a decade of the IGS [Meindl, 2005].

A wide variety of GNSS (GPS/GLONASS) solutions are computed at CODE. Table 1 gives an overview of the analysis products made available through anonymous ftp. In addition, a regional analysis considering a sub-network of about 50 stations of the European permanent network is processed on a daily basis. Weekly coordinate solutions in SINEX format are regularly delivered to EUREF (European Reference Frame, Subcommission of IAG Commission X).

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[1] Technical University of Prague, Czech Republic
[2] Technical University of Munich, Germany
[3] Swiss Federal Office of Topography (swisstopo), since September 1, 2004

Table 1: CODE GNSS analysis products made available through anonymous ftp.

CODE ultra-rapid GNSS products, available at `ftp://ftp.unibe.ch/aiub/CODE`	
COD.EPH_U	Ultra-rapid GNSS orbits (latest update)
COD.ERP_U	Ultra-rapid GNSS ERPs belonging to ultra-rapid orbits
COD.TRO_U	Ultra-rapid GNSS troposphere product, SINEX format
COD.ION_U	Ultra-rapid GNSS ionosphere product, Bernese format
CODE rapid GNSS products, available at `ftp://ftp.unibe.ch/aiub/CODE`	
CODwwwwd.EPH_R	Rapid GNSS orbits
CODwwwwd.EPH_P	24-hour GNSS orbit predictions
CODwwwwd.EPH_P2	48-hour GNSS orbit predictions
CODwwwwd.EPH_5D	5-day GNSS orbit predictions
CODwwwwd.ERP_R	Rapid GNSS ERPs belonging to rapid orbits
CODwwwwd.ERP_P	Predicted GNSS ERPs belonging to 1-day predicted orbits
CODwwwwd.ERP_P2	Predicted GNSS ERPs belonging to 2-day predicted orbits
CODwwwwd.ERP_5D	Predicted GNSS ERPs belonging to the 5-day predicted orbits
CODwwwwd.CLK_R	Rapid GPS clock product, 5-minute values for stations, 30-second values for satellites, clock-RINEX format
CODwwwwd.TRO_R	Rapid GNSS troposphere product, SINEX format
CORGddd0.yyI.Z	Rapid GNSS ionosphere product, IONEX format
COPGddd0.yyI.Z	1-day or 2-day GNSS ionosphere predictions, IONEX format
CODwwwwd.ION_R	Rapid GNSS ionosphere product, Bernese format
CODwwwwd.ION_P	1-day GNSS ionosphere predictions, Bernese format
CODwwwwd.ION_P2	2-day GNSS ionosphere predictions, Bernese format
GLOwwwwd.EPH_5D	5-day GLONASS orbit predictions (based on broadcast info)
CGIMddd0.yyN_R	Improved GNSS Klobuchar-style coefficients, RINEX format
CGIMddd0.yyN_P	1-day predictions of improved Klobuchar-style coefficients
CGIMddd0.yyN_P2	2-day predictions of improved Klobuchar-style coefficients
P1P2.DCB	Sliding 30-day GNSS P1-P2 DCB solution, Bernese format
P1C1.DCB	Sliding 30-day GPS P1-C1 DCB solution, Bernese format
CODE.DCB	Merged P1-P2 and P1-C1 DCB product, Bernese format
CODE final GNSS products, available at `ftp://ftp.unibe.ch/aiub/CODE/yyyy`	
CODwwwwd.EPH.Z	Final GNSS orbits
CODwwww7.ERP.Z	Final GNSS ERPs belonging to final orbits, values for full week
CODwwwwd.CLK.Z	Final GPS clock product, 5-minute values for stations, 30-second values for satellites, clock-RINEX format
CODwwwwd.TRO.Z	Final GNSS troposphere product, SINEX format
CODwwwwd.ION.Z	Final GNSS ionosphere product, Bernese format
CODGddd0.ION.Z	Final GNSS ionosphere product, IONEX format
CGIMddd0.yyN.Z	Improved GNSS Klobuchar-style coefficients, RINEX format
CODwwww7.SNX.Z	Weekly GNSS SINEX product
CODwwww7.SUM.Z	Weekly GNSS analysis summary files
P1P2yymm.DCB.Z	Monthly GNSS P1-P2 DCB solutions, Bernese format
P1C1yymm.DCB.Z	Monthly GPS P1-C1 DCB solutions, Bernese format

Changes in the Daily Data Processing Carried out for IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. Table 2 gives an overview of the major changes implemented during the years 2003 and 2004. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (specifically at `ftp://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn`).

Table 2: Modifications in the CODE processing, from January 2003 through December 2004.

Date	Doy/Year	Description
19-Feb-03		Extraction of GPS broadcast group delay (GD) values in form of Bernese DCB files started
27-Mar-03	082/04	Specific ocean loading coefficients corrected (FES95.2)
01-Apr-03	088/03	Ocean loading coefficients based on a new model (GOT00.2)
01-Apr-03	082/03	The set of reference sites used for geodetic datum definition is checked automatically and adjusted in case of inconsistencies/outliers (e.g. due to earthquakes)
28-Apr-03	117/03	Troposphere time resolution changed from 4 to 2 hours in rapid analysis
30-Apr-03	117/03	GPS/GLONASS-combined ionosphere analysis commenced
01-May-03	120/03	Rapid GNSS (GPS/GLONASS-combined) analysis started (announced in [Schaer et al., 2003a])
29-May-03	147/03	Isolated IGLOS stations included in final (GPS) analysis
08-Jun-03	158/03	Final GNSS analysis started (announced in [Schaer et al., 2003b])
26-Jun-03	158/03	Troposphere parameterization switched from piecewise constant to piecewise linear representation (including gradient parameters)
29-Jul-03		Usage of a completely new version (5.0) of the Bernese Processing Engine (BPE) generally established for the CODE processing
30-Jul-03	211/03	Real ultra-rapid GNSS orbit generation started (announced in [Schaer et al., 2003c])
09-Sep-03	252/03	Refined weighting scheme for ultra-rapid GNSS orbits
16-Sep-03	257/03	Geometric part of phase windup considered in zero-difference processing
29-Oct-03	299/03	IERS 2000 subdaily pole model implemented
01-Nov-03	303/03	Hourly RINEX observation files are merged for daily processing in order to support data flow of daily RINEX files
05-Jan-04	005/04	Uninterrupted orbit generation for GNSS (particularly GPS) satellites being repositioned (announced in [Schaer et al., 2004])
15-Jan-04	018/04	Regular estimation of GNSS satellite antenna phase center patterns (in addition to corresponding offsets) initiated
01-Apr-04	092/04	Refined procedure when merging hourly observation files
06-Apr-04	095/04	Generation of high-rate (30-second) GPS satellite clock corrections
29-Apr-04	120/04	POD on the basis of phase-only tracking data enabled (specifically for R06, the first GLONASS-M satellite)
07-Jul-04	186/04	Tidal step 2 corrections updated to IERS standards
14-Jul-04	193/04	Computation of solid Earth tides step 2 corrected
06-Aug-04	214/04	Unintended GLONASS ambiguity resolution stopped in final analysis

14-Sep-04	257/04	Generation of a GNSS-based ionosphere product for NRT (or ultra-rapid) applications started
01-Dec-04	333/04	Data from fast-moving polar station Amundson-Scott (AMUN) considered in GNSS ionosphere, GNSS orbit and GPS clock computation (see also IGS Report 12031)
15-Dec-04	347/04	Update from JPL DE200 to DE405 ephemeris; ocean tide model changed to CSR30
21-Dec-04	355/04	Maintenance of "endless" orbit prediction with respect to all temporarily inactive (or "disappearing") GNSS (particularly GLONASS) satellites established (for orbit initialization purposes)

Besides various improvements concerning analysis scheme refinements and model updates, there were a few changes entailing a widespread impact. A major step forward was the incorporation of the GLONASS satellite system throughout all analysis steps, with the exception of the determination of precise clock offsets. This led to strictly integrated GPS/GLONASS-combined products (with best possible consistency in terms of geodetic datum definition). Starting on July 30 in 2003, CODE's preliminary ultra-rapid orbit product (a pure prediction generated on the basis of daily rapid orbit solutions) was replaced by a near-real-time product now generated on the basis of hourly observation data. As a consequence of this, our ultra-rapid submissions were officially included in the corresponding IGS ACC combination process. It is worth mentioning that the newly established CODE ultra-rapid orbit product did cover both the GPS and the GLONASS satellite constellation from the beginning.

Since the beginning of 2004, CODE GNSS orbit products include positions and clock offsets for repositioned (GPS) satellites. The estimated time (mean epoch of event) and velocity change components are reported in the CODE analysis summary files.

Finally, we have to emphasize the model change related to the generation of high-rate satellite clock corrections (started on April 5, 2004). Resulting clock-RINEX files containing 30-second clock values for all active GPS satellites are provided to the IGS community.

The following sections detail on the respective changes mentioned above.

General Model Changes and Refinements of Analysis Strategy

Several model changes were related with the implementation of the IERS Conventions 2003 (see Table 1). In October 2003, the IERS 2000 subdaily pole model was enabled. Since December 2004, the DE405 JPL ephemerides and CSR3.0 ocean tide model are used. At the beginning of July 2004, the IERS 2000 tide model for computation of site displacements due to solid Earth tides was implemented. Shortly after, a bug in the computation of the step 2 correction (frequency-dependent part) was identified (incorrect time argument). The error was already present in the IERS 1996 implementation.

The effect of the error is a regionally correlated station height error of up to about 1 cm. CODE SINEX submissions starting with GPS Week 873 (September 29, 1996) up to GPS week 1278 (July 10, 2004) are affected. Starting with GPS week 1279, CODE analysis results are no longer affected by this software bug. As the corresponding error cannot be compensated in a strictly correct way at SINEX level, correspondingly corrected SINEX files were not resubmitted to the

IGS. However, a subroutine that applies a mean correction to the station position part of the solution vector in SINEX files is available from CODE side (at request) and was provided to Rémi Ferland for coarse correction of CODE SINEX files for the IGS cumulative solution and ITRF2004 contribution.

Since April 2003 the ocean tide loading coefficients used are no longer based on FES95.2 but on GOT00.2. Since September 2003, the geometric part of the phase windup is considered for computation of clocks. To be more precise, solely the part of the phase windup due to the varying relative position of a satellite and the stations (but not of the satellite's attitude) is taken into account. Station troposphere modeling was refined in June 2003 by implementing a piecewise linear representation for zenith delays as well as gradients (as already implemented for all other time-dependent parameterizations). The analysis procedure guarantees a continuous representation (even) over midnight. In October 2003, an automatic ionosphere re-analysis scheme with a delay of 30 days was implemented. In February 2004, the priority for stations at timing laboratories was increased for clock analysis.

In April 2003, a procedure was implemented into the final weekly analysis allowing for an automatic check of IGS reference sites for datum definition: Helmert residuals of coordinates from IGS fiducial sites derived from a minimum-constrained solution with respect to the a priori coordinates are analyzed. Sites with residuals bigger than 10 mm in horizontal and 30 mm in vertical direction get rejected from the datum definition. This allows, e.g., automatic exclusion of stations affected by an earthquake from the list of datum defining IGS fiducial stations.

Since December 2004, the South polar non-IGS station Amundsen-Scott (AMUN) is considered in orbit and clock analysis (in ionosphere analysis already since January 2003). Linear motion due to displacement on the glacier of 2.7 cm per day (10 m/year!) is taken into account in the daily analysis. The AMUN station does help to improve the station network layout in Antarctica due to its isolated location . In addition, we may gain experience in data analysis from a (comparably) fast moving station (that is moreover exposed to extreme weather conditions).

The automatization of the processing was further refined, on one hand by making use of the new version (5.0) of the Bernese Processing Engine (BPE) in July 2003, on the other hand by a sophisticated alerting mechanism in case any irregularities in the processing sequence are identified. Automatic checkers do not only verify the quality and completeness of the products but identify any failure in processing chains, of computers, disks, archiver, tools, ftp access, etc. Connections to data centers, the near-real-time data flow, as well as the GNSS satellite constellation status are checked every 30 minutes. If problems are identified, corresponding alarms are issued by e-mail and short messages to the cellular phone (or computer terminal) of the operator in duty.

GPS/GLONASS-Combined GNSS Analysis

After careful monitoring of GLONASS data availability, latency, and completeness from GPS/GLONASS combined IGS/IGLOS receivers, combined GPS/GLONASS analysis was switched on in several steps: Starting on April 18, 2003, consistency of GLONASS frequencies in broadcast navigation data was checked, on April 30, GPS/GLONASS-combined ionosphere analysis was commenced, and on May 1, combined rapid orbit analysis started [Schaer et al., 2003a]. GLONASS orbits had to be filtered out for the IGS submission at that stage. After inclusion of data from isolated combined receivers on May 29, first GLONASS orbits were computed in the final analysis and submitted to the IGS as of doy 159/2003 (GPS week 1222)

[Schaer et al., 2003b]. Since then all CODE analysis products, except of clocks, are based on a fully combined GNSS analysis. CODE final, rapid as well as ultra-rapid submissions do cover the complete GLONASS constellation.

Initially, 37 GNSS satellites (29 GPS plus 8 GLONASS) were included in the solutions. This number increased to 41 satellites (30 GPS plus 11 GLONASS) at the end of 2004, including the new GLONASS-M satellite, R06. The combined analysis started with a typical number of a dozen GPS/GLONASS baselines. The number of available baselines increased to typically 25 at the end of 2004 (see Figure 1). Particularly harmful are occasionally missing data from Australian stations for the rapid and ultra-rapid analysis. Since a significant number of mixed receivers does not track unhealthy satellites, the number of baselines for these satellites is typically between 1 and 10 baselines. At several occasions, the orbit of a GLONASS satellite was estimated with a single baseline only (in a specific case even just on the basis of phase-only tracking data). Thanks to 3-day arc analysis, thus obtained orbits were still of acceptable quality.

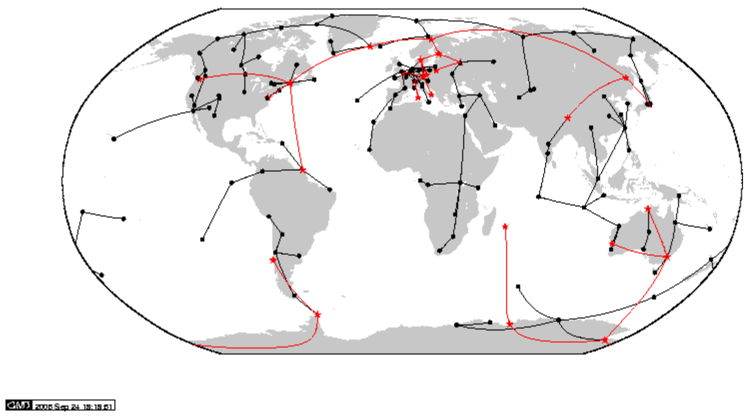

Figure 1: Baselines as processed at CODE on doy 365/2004. Mixed GPS/GLONASS baselines are indicated in red.

Orbit overlaps as well as SLR validation indicate an orbit quality for the CODE GLONASS final orbits of about 5 cm 1-D RMS. Figure 2 shows O-C SLR residuals covering a time interval of one year for the three satellites R04, R22, and R24 that are tracked by the ILRS. Table 3 gives the mean bias and standard deviation of the residuals for the three defined GLONASS and the two GPS satellites equipped with retro-reflectors [Urschl et al., 2004]. Note that the observed SLR bias is significantly smaller for GLONASS satellites than for GPS satellites, for which the (still unexplained) bias of 5–6 cm persists.

Table 3: SLR residual statistics wrt CODE final orbits, for the GNSS satellites tracked by ILRS.

Satellite		Time period	# Normal points	Bias [cm]	Std [cm]
GLONASS	R05	2003.4–2004.4	3911	–2.2	±5.0
GLONASS	R22	2003.4–2004.4	8149	–2.6	±4.4
GLONASS	R24	2003.4–2004.4	4441	–2.2	±5.2
GPS	G05	2001.0–2004.3	9380	–5.4	±2.6
GPS	G06	2001.0–2004.3	9216	–6.1	±2.9

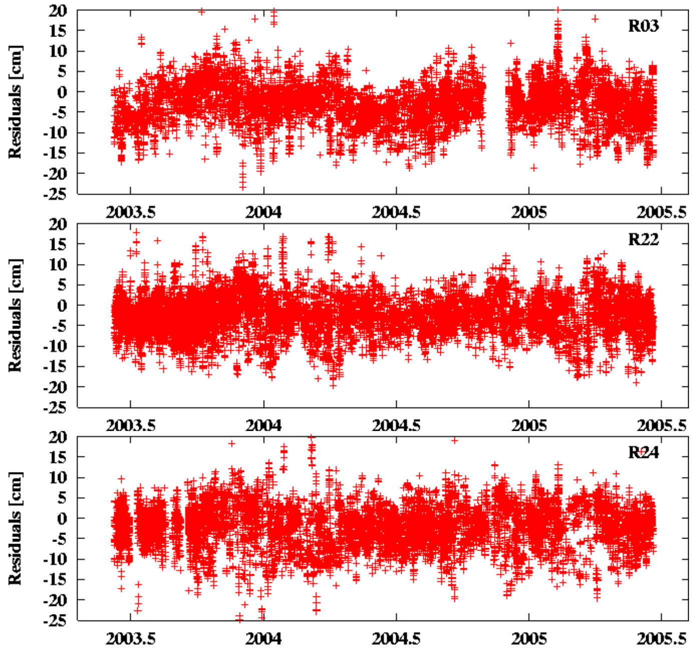

Figure 2: O-C SLR residuals wrt GLONASS satellite orbits from CODE.

Ultra-Rapid Products

Prior to June 30, 2003 (GPS week 1225-1), CODE generated ultra-rapid orbits which were pure extrapolations of daily rapid orbits. Due to this preliminary product status, the submissions were not used in the IGS AC combination process, i.e., they did not contribute to the official IGS ultra-rapid product, but were included for comparison purposes, only.

The situation changed on doy 181/03 when a revised processing scheme came into operation at the CODE analysis center [Schaer et at., 2003c]. The ultra-rapid produced from that day on is now strictly based on near real-time (NRT) GNSS tracking data. The orbit updates are strengthened by incorporating historical rapid information for long-arc orbit combination on normal equation level. The generated orbits are complete with respect to all transmitting satellites, even the GLONASS constellation was covered from the very beginning. Consequently, CODE's ultra-rapid contribution now is fully included in the IGS ACC combination process, the effects of which can be nicely observed in Figure 3.

An elaborate procedure to determine reliable accuracy codes for all GNSS satellites was implemented. The scheme is based on orbit fits of differing arc length, the historical performance of GPS satellites in previous IGS orbit combinations, eclipse intervals, health status, and several other parameters. Orbit predictions are based on a fit interval that gets optimized individually for each satellite.

No clocks are computed for the ultra-rapid delivery due to very limited computer resources. For the same reason, the 06-UT ultra-rapid update is generated o the basis of the previous 24-UT update and the following rapid analysis, respectively.

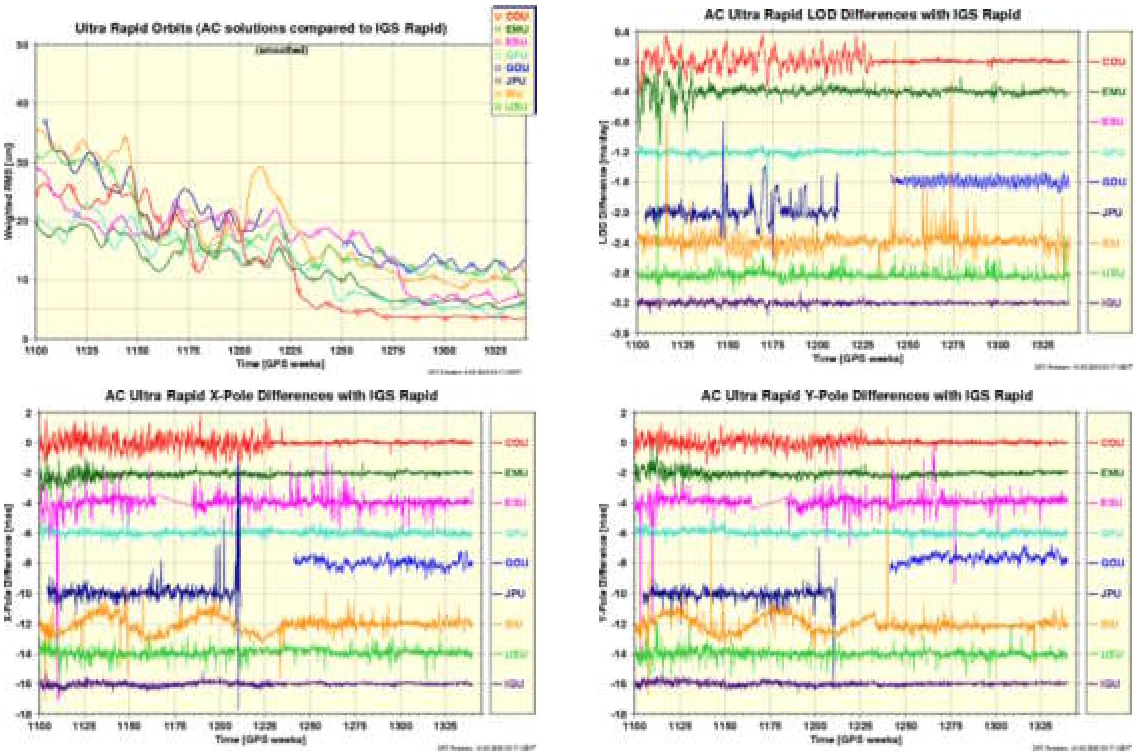

Figure 3: Comparison of individual AC solutions (orbit, X-/Y-pol, LOD) wrt IGS rapid (plots downloaded from IGS ACC website, `http://gfz-potsdam.de/pb1/igsacc/index_igsacc.html`).

Observation Data Management and Monitoring

Being now, for the ultra-rapid analysis, relying on the near real-time (hourly) RINEX observation data, a significant effort was put into the development of download procedures to maintain a reliable and solid data flow. Data is downloaded from all accessible global and regional data centers – and some data is downloaded even directly from local servers – to get the data as early as possible. Data files from different sources are merged in order to get complete data files. The GNSS datapool maintained at CODE is, in particular wrt mixed GPS/GLONASS station data, probably the most complete data source (with shortest data latency).

The same procedures allow for a detailed monitoring of observation file availability, latency, and completeness at the different data centers, an undertaking that revealed numerous problems. To identify and sort out such data-flow problems several extensive statistics are created on a regular basis and made available via anonymous ftp (`ftp://ftp.unibe.ch/aiub/igsdata/`). These files include information on, e.g., completeness, reliability, observed satellites, minimum and mean delay at the different data centers for all available hourly RINEX files. A number of encountered data flow problems were addressed via IGS Mail.

Handling of Brand New and Repositioned Satellites

Starting with beginning of 2004, satellite maneuvers are monitored, maneuver epoch and velocity change are determined and orbits before and after the event are provided in the precise orbit files (making use of the maneuver flag available in SP3c.) Maneuver parameters are documented in CODE's weekly analysis summaries beginning with GPS week 1252.

As initial information for a satellite maneuver the approximate repositioning epoch published in the NANU messages is used. The orbit for the satellite is split at this orbit and independent arcs are computed before and after the maneuver. The closest approach of the arc before and after the maneuver defines the maneuver epoch, the velocity difference of the two arcs at this epoch defines the velocity change induced by the boosters.

The orbit arc after the maneuver is initialized using double-differenced GPS/GLONASS pseudorange observations (from those stations tracking unhealthy satellites). Maneuver epoch and velocity change are improved iteratively. Using phase double-differences the orbit parameters of the two arcs are improved further and finally stabilized by combining the arcs with arcs from the previous and finally from the following day (see Figure 4, left). The entire procedure runs automatically and allows it to determine the middle epoch of the maneuver up to one second. The procedure does not require any broadcast information. Note that the maneuver is not modeled physically but the orbit representation is replaced by a new arc at the maneuver epoch.

Phase data residuals reveal the period (typically a few minutes, depending on DV) during which the data has to be removed before and after the maneuver. Note that consistency of orbits and clocks through the maneuver are guaranteed at the phase level. It is important to note, too, that the procedure is inflicted by a reduced number of observations due to the fact that a significant number of IGS/IGLOS stations do not sample satellites marked unhealthy. Furthermore, it is worth mentioning that users of the Bernese GPS Software V5.0 (also V4.2) did probably not really realize that IGS (de facto CODE) orbit information with respect to repositioned satellites got successfully processed in their analysis (e.g., EUREF analysis).

The main component of velocity changes induced by maneuvers is along-track. Velocity changes of the 27 maneuvers observed in 2004 typically have a magnitude of a few 100 mm/s. The largest velocity change found was 2653 mm/s (PRN G02, doy 336/2004) followed by a maneuver of a similar size for the same satellite the following day; the smallest velocity change was 46 mm/s (PRN G28, doy 226/2004).

The orbit initialization procedure allows it to determine the orbit of a brand-new satellite as soon as signals are tracked by the IGS/IGLOS ground network, even before broadcast information of the new satellite is available. As initial information the announced orbital plane and slot number are sufficient. Beginning with PRN G22, launched on December 20, 2003, orbit and clock products are delivered to the IGS for new satellites as soon as first tracking data is available. The sequence of events following the launch of G22 is shown in Figure 4 (right). In 2004, the described procedure was successfully applied to the new satellites R04 (doy 029), R06 (doy 031), R02 (doy 043), G19 (doy 085), G23 (doy 181), and G02 (doy 318).

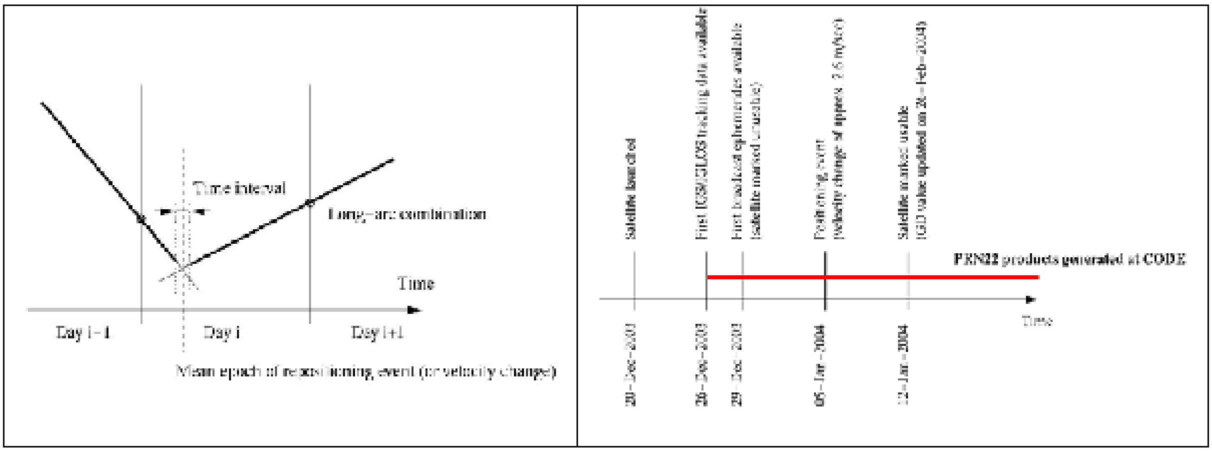

Figure 4: Left: Orbit determination scheme for repositioned satellites. Right: Chronology of GPS Block-IIR satellite launch (PRN22/SVN43).

Estimation of High-Rate Clock Corrections

On April 5, 2004, the CODE analysis center started to generate high-rate (30-second) satellite clock corrections on a daily basis for the rapid as well as for the final product. All clock-RINEX files delivered to the IGS contain high-rate clock corrections for all GPS satellites starting with doy 095/2004 for the rapid, and with doy 094/2004 for the final product submissions (see IGS Mail 4913).

The high-rate clock corrections are based on a phase-consistent interpolation of precise 5-minute clock results using time-differences of phase observations [Bock et al., 2000]. Data from 90 stations (rapid) and 120 stations (final) are used, respectively. Coordinates, troposphere parameters, and orbits are introduced from a global double-difference GNSS network analysis and kept fixed. 5-minute clock corrections from a global zero-difference GPS network analysis are used as anchor points. Care is taken that orbits and coordinates used for the zero-difference analysis and for the clock interpolation are consistent.

Phase observation time-differences are formed whereby the phase ambiguities are eliminated. The phase-differences are screened for outliers and cycle slips are identified. Based on these cleaned differences of phase observations, time-differences are estimated for all clocks in the system. In a next step, clock values are generated, basically by integrating the clock time-differences. Constraining the time series of clock values to the 5-minute input clocks eliminates the remaining arbitrary offset. A drawback of the efficient procedure is that covariance information for the estimated clock values is not available.

The interpolated clock values are written in a clock-RINEX file together with the unchanged 5-minute clock values. Alignment and reference clock are taken over from the 5-minute clocks. Validation using precise point positioning showed that the quality of these clock interpolations is comparable with that of the original 5-minute clock values.

Outlook

A major focus in the IGS is the switch to absolute antenna phase patterns. As this subject is closely related to satellite antenna patterns, CODE commenced the routine estimation of GNSS satellite antenna patterns (in conjunction with offsets) in January 2004. As a matter of course, GLONASS antenna offsets and patterns are estimated in the same procedure and will be made available.

Currently not yet possible due to limited computer resources is the computation of satellite clocks for the ultra-rapid deliveries. We look for alternatives allowing to solve the current problems with available computing power. Precise GLONASS clock corrections, too, are not yet computed (for GNSS PPP applications). Implementations are planned to cope with frequency dependency of differential code biases (concerning GLONASS observation data).

Future developments will cover time transfer with GPS carrier phase measurements, comparisons of SLR and microwave observations in order to reinvestigate the origin of the persistent 5-cm bias between the two observation techniques. Consideration of higher-order ionospheric corrections is intended. Orbit determination techniques for Low Earth Orbiters are further refined and more experiments for combined analysis of high and low orbits are foreseen. Experiments with orbit determination for geosynchronous EGNOS satellites are underway [Meindl et al., 2004]. Last but not least, implementation of GALILEO into our software is planned in a project with Bundesamt für Kartographie und Geodäsie, Frankfurt, Germany, in order to be ready for the new constellation as soon as signals get available.

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The ESA/ESOC IGS Analysis Centre
Annual Report 2003-2004

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Introduction

This Report gives an overview of the ESOC Analysis Centre activities and a presentation of the IGS activities at ESOC during the period 2003-2004.

There has been a major change to the routine processing during the period, as outlined and described below, which includes the use of an ambiguity fixing strategy. During this time the ESOC AC activities have continued uninterrupted and have consolidated with the timely delivery of all the products part of the IGS and participation in several of the IGS Working Groups and Pilot Projects.

Currently ESOC's GPS-TDAF (Tracking and Data Analysis Facility) handles automatically the ESA ground receiver network, the IGS network data retrieval and storage and all of the routine daily and weekly data processing of the different IGS products. The system is capable of performing autonomous operations for several days, the processing of the final products is more manual to be able to detect and correct errors and inconsistencies and thus provide the best possible products.

Changes and activities in 2003-2004

These have been the changes to IGS activities at ESOC during the period:

Jan 2003	*IGS processing*: Changed the processing during satellite eclipses from excluding the data during eclipse periods and introducing a manoeuvre at the eclipse exit to <u>leaving all the data in</u> and <u>not</u> including a manoeuvre at the eclipse exit.
May 2003	UltraRapid processing: Switched from using 30 stations to 40 stations, thus improving the solution.
November 2003	GPS Processing: Introduced Ambiguity Fixing in the Finals using Wide-Lane, Narrow-Lane combination to truncate ambiguities and re-run with best possible passes.
September 2003	GLONASS : Started orbit estimation for new satellites R21, R22, R23
January 2004	Implemented ITRF IGb00

February 2004	GPS Processing: Rapid and UltraRapid orbits changed to Ambiguity Fixing proc. GLONASS : Started orbit estimation for new satellites R04, R02 (R06; soon!) UltraRapid processing: Switched to 6 hour updates.
July 2004	Parameterization from solar radiation pressure extended force model changed to improve ultra rapid orbits.
September 2004	Integration step size changed for a better reproduction of eclipse enter and exit.

Routine Activities

ESOC participates in the IGS as an Analysis Centre providing the following routine products either to the Analysis Centre coordinator or to the IGS Global Data Centre CDDIS:

- Final GPS Orbits plus clock biases
- Final GLONASS Orbits plus clock biases
- Rapid GPS Orbits plus clock biases
- Twice Daily Ultra-Rapid GPS Orbits plus clock biases
- Daily Rapid EOP file
- Daily Ultra-Rapid EOP file
- Weekly final EOP file
- Weekly final processing summaries
- Weekly free network solution in SINEX format
- Daily final tropospheric files
- Daily final ionospheric files in IONEX format
- Weekly combined IGS ionosphere IONEX files; ESOC is the IGS Ionosphere Associate Combination Center (IACC)
- Daily rapid RINEX clock files with 5 minutes sampling
- Daily final RINEX clock files with 5 minutes sampling

Processing Method

The ESOC GNSS precise orbit determination processes for all the cases are based on a batch least squares estimation solution of RINEX IGS station data using various numbers and distributions of stations based on availability, past performance and processing time available. The average numbers of stations used for each of the processes at ESOC are as follows:

- Final GPS POD: 52 stations
- Final GLONASS POD: 27 to 30 stations
- Rapid GPS POD: 40 to 45 stations
- Ultra-Rapid GPS POD: 40 to 45 stations

The estimation method for all the POD activities uses an in-house estimation program, BAHN, currently in version 9, which can handle most types of data for satellite POD activities (ranges, range rates, SLR, Doris, Prare, altimetry, GNSS observables in undifferenced, and double-differenced modes). The quantities estimated by the program are variable depending on the focus of the run. For the IGS submissions the quantities estimated are:

- The station coordinates,
- The satellite state vectors,
- The solar radiation pressure extended force model parameters,
- Cycle-per-revolution empirical accelerations,
- The undifferenced carrier phase ambiguities for the ionospheric-free linear combination,
- The GPS-GLONASS receiver biases (for the GLONASS processing only),
- The Earth rotation parameters: x and y pole position and rates and Length of Day,
- The tropospheric zenith delay for every station every 2 hours,
- Station and satellite clock biases, estimated as time-dependent parameters (one value for every observation epoch).

More information on our routine GPS and GLONASS processing, processing description, model usage, result plots, etc can be found at:

```
http://nng.esoc.esa.de/
http://igscb.jpl.nasa.gov/igscb/center/analysis/esa.acn
```

Ambiguity fixing strategy

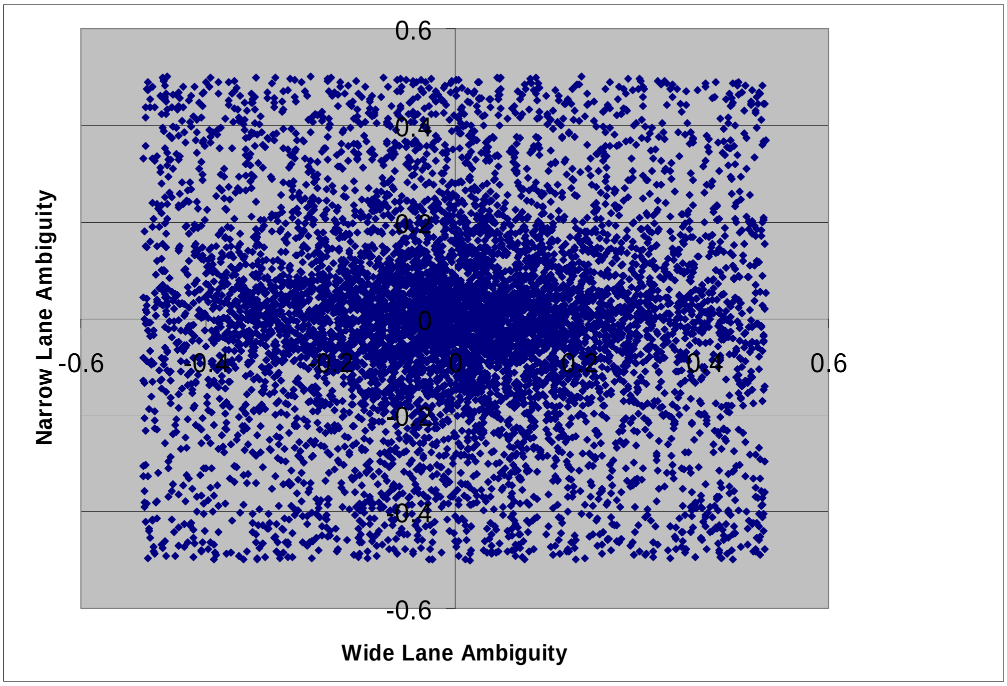
By the end of 2004 the computation of orbits started to be done following an ambiguity fixing strategy.

It is a double differences approach to eliminate satellite and receiver non-integer biases using a linear combination of observables (wide and narrow lanes). The method is based on the pseudorange, since the wide lane is resolved by using it. Good quality data as delivered by the high quality geodetic receivers is needed to properly work.

The narrow lane is resolved after initial POD estimation of the floating ambiguities. The needed orbit accuracy for truncation is of less than 5 cm (one half of the narrow lane wave length). A second POD is needed with ambiguities fixed from the first step. It is computationally very fast.

The plot below corresponds to a typical run. Every marker represents a pass from which the estimated narrow and wide lengths can be read from the axis. Concentration of the points in the area close to (0,0) is a condition for the method to work since ambiguities are truncated to the nearest integer.

The implementation demonstrated a better consistency of the products with the ones estimated with other techniques like laser. The overlapping of consecutive orbits was also improved.



WIDE LANE VS. NARROW LINE AMBIGUITIES FOR A TYPICAL RUN

GLONASS Processing

Processing of the GLONASS precise orbits has continued uninterrupted during the reported period. The orbits have been generated correctly with a diminishing time delay. Currently the processing delay is the same as the IGS finals (7 days).

During the period reported here the GLONASS processing has been merged into the routine IGS final processing. The process still uses the ESA GPS final orbits as fixed orbits to calculate the GLONASS orbits from dual-system receivers, it is all now processed as part of the normal processing steps of the IGS finals.

Ionosphere Processing

Routine processing of ionospheric Total Electron Content (TEC) maps and satellite/receiver differential code biases (DCBs) continued during 2003 to 2004.

The ionosphere processing in final mode continued (and since 2004 also in rapid mode) with the rapid orbits. The daily routine ionosphere processing in 2003-2004 has been as follows:

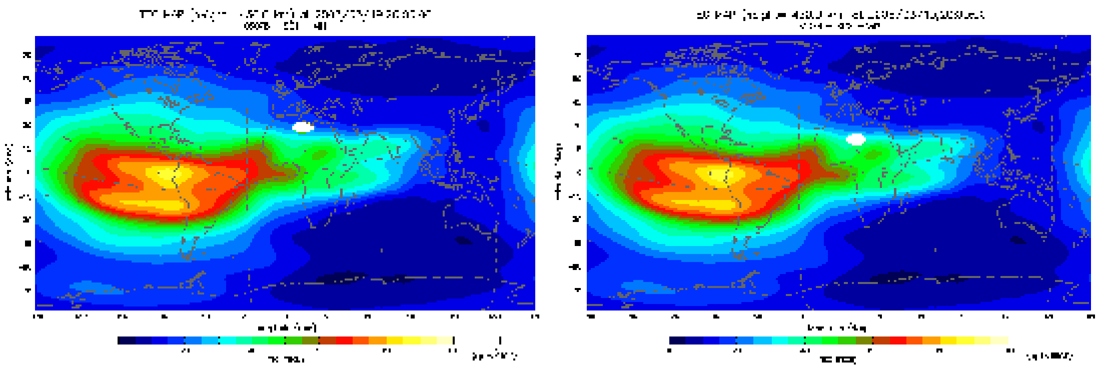
1) A nighttime TEC data fit was made to obtain a set of reference DCB values for that day. The nighttime TEC itself was absorbed in this fit with low degree and order spherical harmonic. In the other fit 2) these DCBs were then introduced as constraints.
2) A Chapman profile model was fitted to the TEC data of that day, where the layer of maximum electron density N0 and its height h0 were estimated as surface functions of geomagnetic latitude and local time. h0 was restricted to have values within a predefined range only, namely 350 km =< h0 =< 450 km or 400 km =< h0 =< 450 km. This run was

the official ESOC contribution to the IGS Ionosphere Working Group to be part of the combination.

In parallel to these routine stuff, comprehensive and far-reaching modifications and tests have been made in the IONMON software in order to establish a sequential estimate processing at ESOC (which is, while this Technical Report is written in September 2005, operational since already 3 months; the Chapman profile approach is retained in the sequential estimate scheme, while nighttime fits were abandoned).

A few time was also investigated into the development of a new multi-layer model for the ionosphere, but this task was treated with less priority and it will take still some time for conclusion.

In the course of 2003, a cross-disciplinary working group of experts from ESOC and ESTEC investigated into the origin for RF link degradations observed on the signals of the Cluster satellites. With the aid of IGS TEC maps they were able to establish an obvious relationship between these signal disturbances and ionospheric scintillations in the region of the dusk equatorial anomaly: The intersection points of the Cluster signals through the ionospheric shell at 450 km on their way down to the ground receiver were marked in IGS TEC maps. Observed Custer signal fluctuations could in this way clearly be related to times, when the marked intersection point did fall into a potential scintillation region on the TEC maps. Figure 1 presents an example of such a case on 19 March 2003 (over 90 % of these fluctuation events occur in the September – December period): SC4 was tracked from Maspalomas, and from 20:40 – 21:00 UT fluctuations were observed on SC4. SC1, SC2 and SC3 were tracked from Villafranca with stable links. The penetration points of the RF links with the ionospheric shell are marked with a white spot in the corresponding 20:00 IGS TEC map of Figure 1. It can clearly be recognized that in the case of SC4 (the bottom right one in Figure 1) the intersection point marked with the white dot is located in the suspicious region of ionospheric scintillation appearance, while the intersection points of SC1, SC2 and SC3 are quite distant from that region.



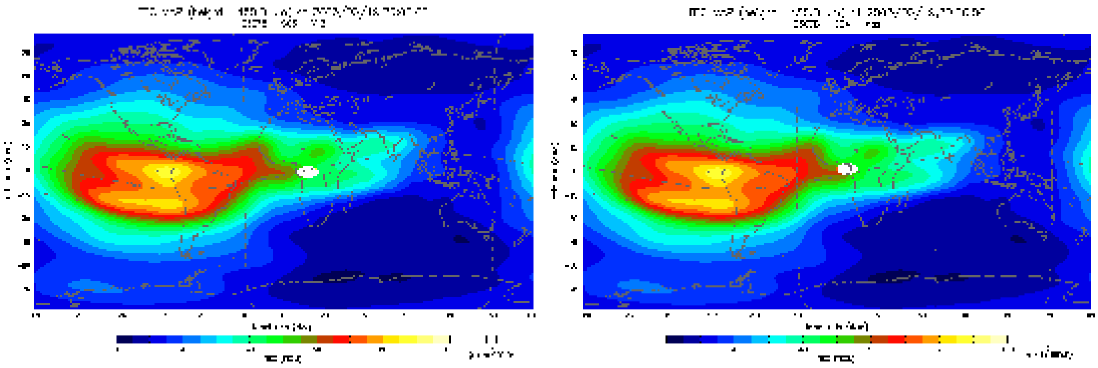


Figure 1. Penetration point of the RF link with the ionosphere, Cluster, 19/03/2003, SC1 (top left), SC2 (top right), SC3 (bottom left), all tracked from VIL, and SC4 (bottom right) tracked from MSP, anomalies were only on SC4.

In the same way, also for the satellites MSG-1 and XMM observed signal disturbances could be related to ionospheric scintillation. For details see Feltens, et al. (2004a) and Feltens et al. (2004b).

In January 2004 ESOC commenced with the performance of routine validations of the individual and combined IGS TEC maps with TEC values derived from the Envisat dual-frequency altimeter. These Envisat validations are run once per week after the combined IGS TEC maps have been processed and are made available by UPC.

LEO Activities

The activities of the ESOC Analysis Centre for the IGS LEO Pilot Project during this period have concentrated on implementing LEO processing capability in the available POD systems, using the data from CHAMP. Because ESOC also coordinates the Pilot Project itself, please refer to the Chapters on the LEO Pilot Project for more information, or consult the igsleo website at http://nng.esoc.esa.de/igsleo.html

Future Activities

ESOC Analysis Centre will remain active during the next year; continue the regular contributions to the IGS orbit and clock products, troposphere, ionosphere, station network solutions and EOPs. In the area of LEO POD significant efforts are underway to completely redesign the LEO calculations. All the processes will be streamlined further and the GPS-TDAF will be improved for more efficient and independent operations, paying particular attention to the GLONASS processing to make it more efficient and to reconsider the processing of GPS and GLONASS orbits together.

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Feltens, J., J.M.Dow, G.Billig, D.Fornarelli, S.Pallaschke, B.Smeds, H.-J.Volpp, P.Escoubet, H.Laakso (2004b): „ Usage of IGS TEC Maps to explain RF Link Degradations by Spread-F, observed on Cluster and other ESA Spacecraft", IGS Presentation, *Proceedings of the 2004 IGS Workshop & Symposium*, Berne , Switzerland, March 1-5, 2004.

GFZ ANALYSIS CENTER OF IGS - Annual Report for 2003-2004

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1 Summary

This report summaries the changes taken place in the routine processing during 2003 and 2004 and focuses on the new developments at the GFZ's IGS Analysis Centers.

Parallel to the routine IGS processing for generating Ultra-Rapid, Rapid and Final products, TIGA data are processed on a routine base as well. We also set up a new processing line for estimation of absolute antenna phase center variations for GPS satellites.

In the software development, a new ambiguity-fixing approach is implemented, which can fix more than 95% of the total independent ambiguities for IGS networks. Absolute phase center variations (PCV) correction and estimation are introduced into the EPOS software package for generating and using IGS official absolute PCVs.

2 Changes in the Routine Processing

During 2003 and 2004 few changes are introduced into our routine processing. They are summarized in Table 1. The first two actions and their impacts on products are already reported in our annual report of the previous year (Gendt et al., 2002).

Table 1. Changes in the analysis strategy

Week	Date	Description
1202	2003-01-19	Introduction of ambiguity fixing into Rapid analysis
1214	2003-04-13	Enlargement of network (~50 station) for Rapid analysis
1239	2003-10-08	Cut-off elevation angle to 7 degrees for Ultra Rapid
1243	2003-11-02	Introduction of ambiguity fixing into Ultra Rapid analysis
1253	2004-01-11	Introduction of IGb00 Coordinates

Figure 1 shows the weighted RMS of GFZ Ultra Rapid orbits with respect to combined IGS Rapid orbits. After having implemented ambiguity fixing, the RMS of Ultra Rapid orbits is reduced significantly from 10 cm to 5 cm.

3 Revised Ambiguity-fixing Approach

In most of the ambiguity-fixing approaches implemented in the IGS data processing, at first, a set of independent double-difference ambiguities is defined, then they are fixed according to their estimates and variances. The fixing efficiency is highly dependent on the selection of this set of ambiguities. In the new approach (Ge et al. 2005), the most easily to be fixed ambiguities are selected according to their estimates and standard derivations of both wide-lane and narrow-lane instead of baseline length or the standard derivation of ionosphere-free ambiguities only. Furthermore the maximum independent ambiguities are searched over the whole network.

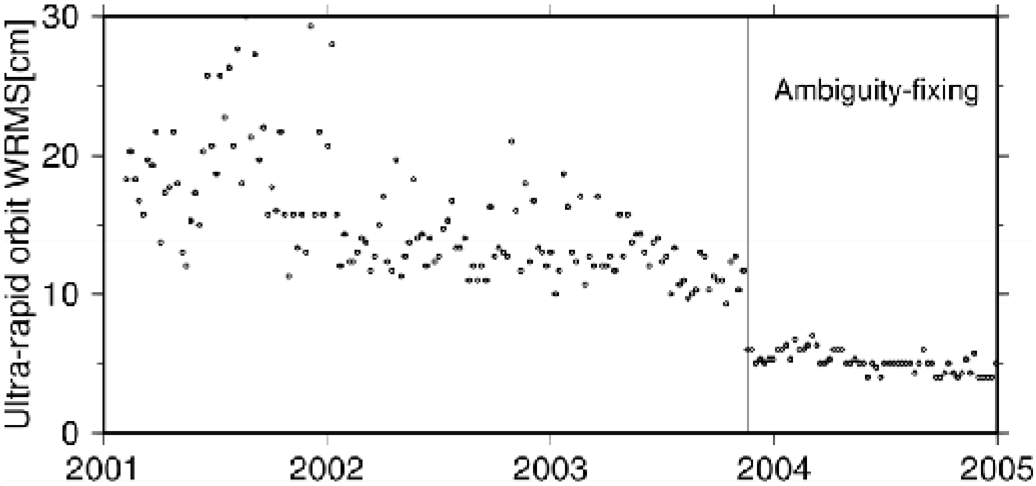

Fig. 1. Quality of the GFZ Ultra Rapid orbit products taken from the official combination reports. Orbit RMS is reduced from 10 cm to 5 cm by fixing ambiguities.

The new approach were validated by analyzing data from a network of 94 IGS stations from days 292 to 327 in 2003 with the new and the commonly used approach. With the new approach 23% more ambiguities are fixed compared to the old method (Fig. 2). That makes the total fixing rate to 97%. As shown in Fig. 3, the newly fixed ambiguities bring an additional improvement for the station coordinate repeatability in the east component, especially for the regions, where the stations are sparse (for example in Africa), and a slight improvement for satellite orbits.

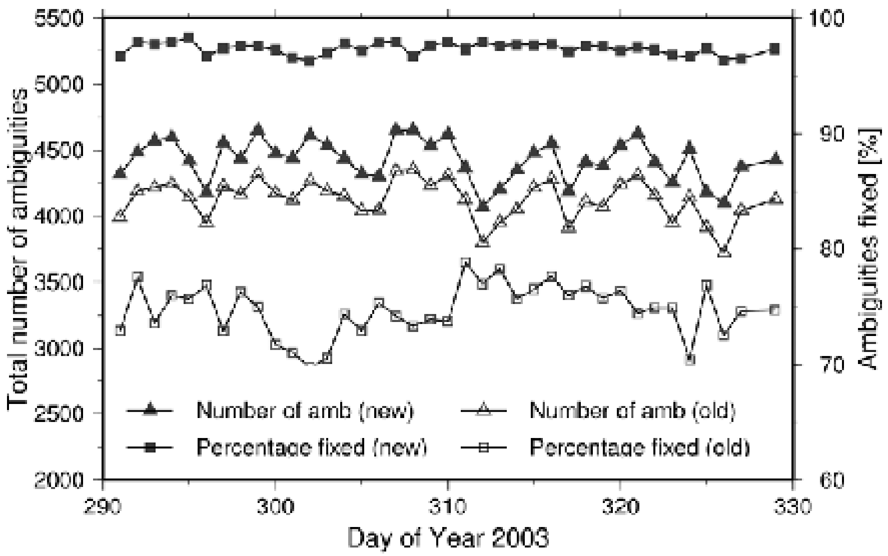

Fig. 2 Total numbers of independent double-difference ambiguities and percentages of fixed ambiguities for the new and a commonly used approach.

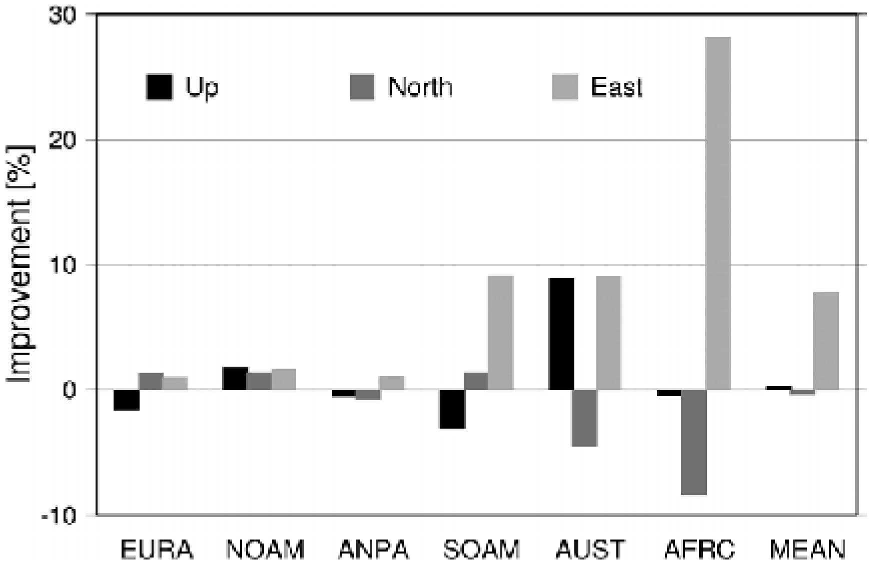

Fig. 3 Improvement by the new method in the repeatability of station coordinates for different regions (EURA, Europe and Asia; NOAM, North America; ANPA, Antarctic and Pacific area; SOAM, South America; AUST, Australia; AFRC, Africa)

4. Estimation of Absolute PCVs for GPS Satellites

The GFZ EPOS software was modified for both using APCV models (for satellites and receivers) and estimating raw PCVs for satellites, following the strategy by Schmid et al. (2004).

Five weeks of data from 90 IGS stations for days 292 to 326 in 2003 were analyzed to estimate satellite APCV models and to validate the IGS proposed APCV models for both satellites and receivers.

The data processing procedure was kept the same as for our IGS routine data processing. We used 24-hour arc length, 5 minute sampling rate, 7º cut-off elevation angle and an elevation dependent weighting. Receiver PCVs and offsets were fixed to the IGS proposed models. For all satellites, raw PCVs were estimated as piece-wise constant functions with the IGS offsets of 2.3384 m and 1.3326 m for II/IIA and IIR as initial values, respectively.

The daily repeatability is better than 1 mm. However, we found significant differences between satellites belong to the same block type, about 10 mm at the boundary areas. This offset inhomogenety is also proven by directly estimating offsets (Ge et al., 2005). Having converted estimates to offset and the 'most flat' PCV, the PCVs show good agreement among satellites belonging to the same Block-type while offsets differ from satellite to satellite. Therefore we suggest to use block-type PCV plus individual offset for each satellite, because ignoring the differences among satellites will lead to a scale bias which changes along with the satellite constellation (Ge et al., 2005). .

Ignoring the difference between satellites, the derived PCV for Block II/IIA and Block IIR agree with the result from TUM within 0.3 and 1.1 mm respectively.

Using IGS proposed receiver and satellite PCVs, a mean shift of -7 mm for zenith troposphere delay is found. This might remove the bias between ZTD from GPS and radiosonder.

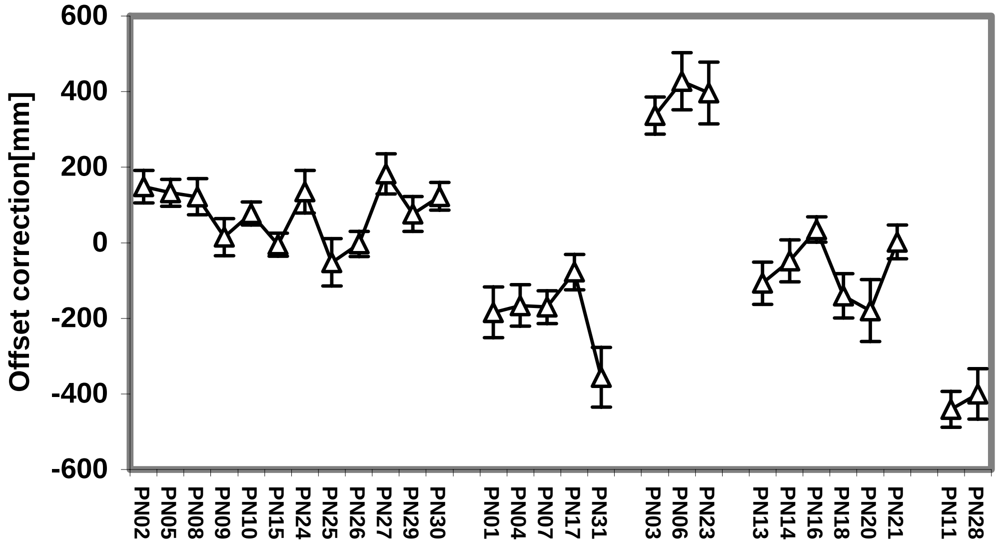

Fig. 4. Mean offsets of the estimated daily offsets for each individual satellite. The first 3 groups are Block II/IIA satellites and the last two are Block IIR.

Based on the test, we set up a new data processing line for estimation of absolute PCVs for GPS satellites. The processing strategy is the same as for the test. Data from 1995 to present are reprocessed. Daily raw PCVs are converted to PCVs and offsets satellite by satellite. There is a trend of about –2 cm/year most likely due to the scale rate bias of the fixed reference frame and an annual fluctuation with amplitude of 10 cm because of the poorly modeled time-dependent station deformation. The repeatability of PCVs is better than 1 mm. .The mean PCVs of each satellite agrees very well with those belonging to the same block-type. The resultant satellite-specific offsets and block-type-specific PCVs are provided for generating the official IGS absolute PCVs for satellites.

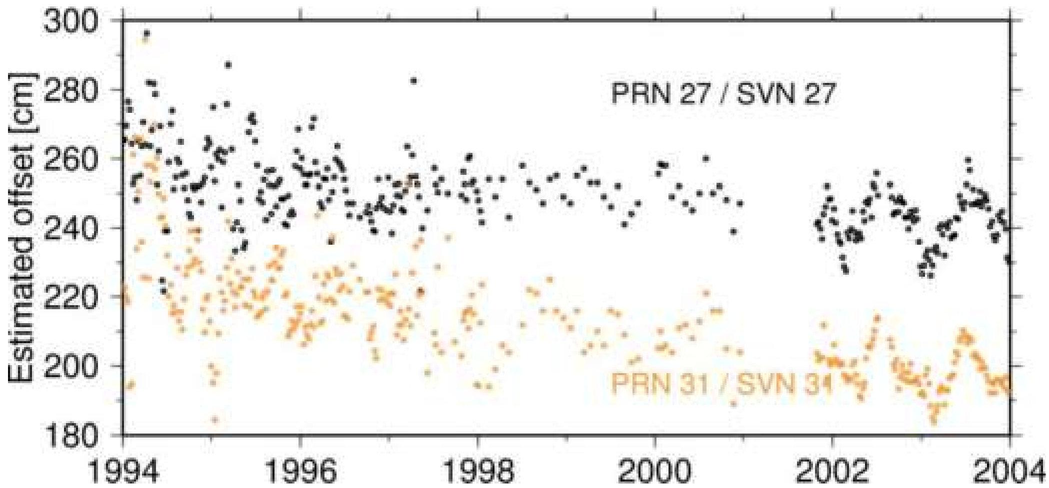

Fig. 5 Weekly estimated offsets for PRN27 and PRN28. The annual fluctuation with amplitude of about 10 cm may be connected with the temporal scale changes due to poorly modeled station

position changes. The trend of about 2 cm / year is most likely due to the scale rate bias of the fixed reference frame.

5. TIGA data processing

The TIGA project has been going on since 2002. Following the cluster strategy implemented in the GFZ IGS AC, 6 TIGA clusters comprising totally 370 globally distributed GPS stations (Fig. 6) have been re-/analyzed. Among them, 3 clusters are for IGS stations and another 3 for TIGA (about 200 stations). The data processing is running in three lines, backward till 1994.0, forward with 66-week delay and another line as part of IGS with one-week latency. So far, the data back to 1994.0 have been analyzed day-by-day and archived as SINEX solutions.

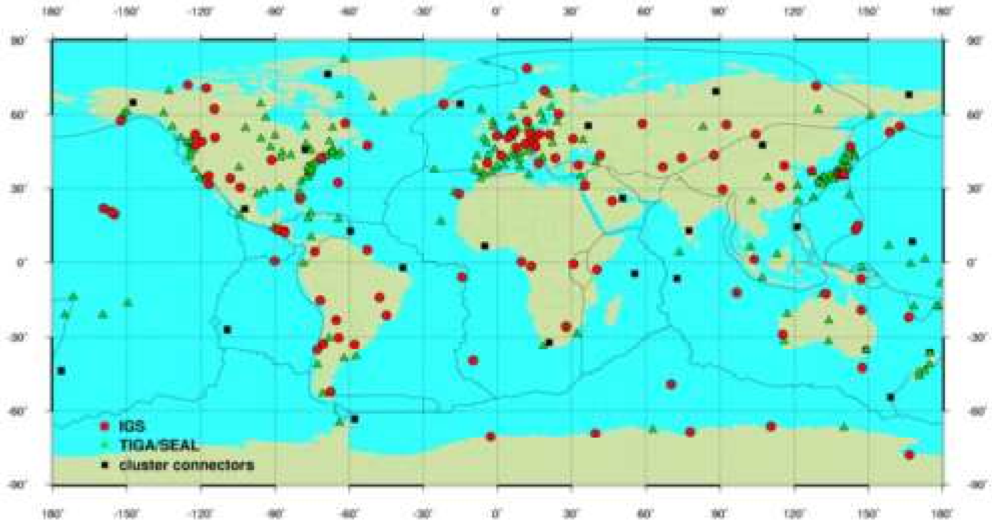

Fig. 6. Global GPS network analyzed in GFZ TIGA AC.

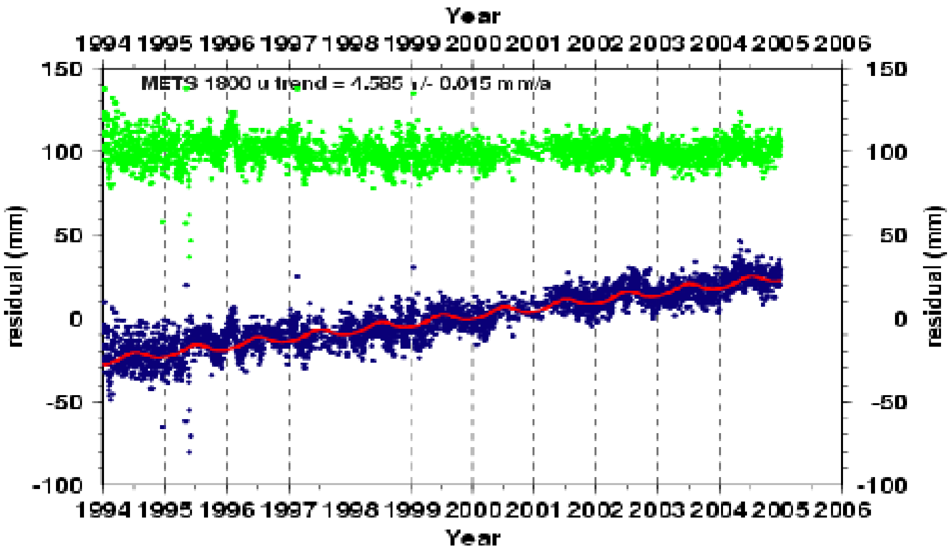

Fig. 7. Height time series of METS (Metsahovi, Finland) and fitting with constant, linear rate, annual and semi-annual waves. (blue: height residual time series; red: fitting line; green: fitting residuals)

Daily time series (example sees Fig. 7) are analyzed to derive vertical motion rates of the TIGA stations by fitting with linear rate and seasonal (annual and semiannual) waves. To improve the accuracy of the estimated vertical rate, atmospheric pressure loading (APL) induced crustal displacement is corrected. A study shows (Zhang, et al., 2005) that applying APL correction can affect the stability of the reference frame at the millimeter level in seasonal scale. However, the effect on the long-term stability of the reference frame can be neglected considering the accuracy requirement of better than 1 mm/a of the vertical rate of the TIGA stations for monitoring the vertical motion of the allocated tide gauges.

While analyzing the consistency of the scale of reference of the solutions, a rapid scale change during year 2000-2001 has been detected (Zhang, et al., 2004). Further analysis showed that the scale change could be caused by the incorrect satellite phase center offsets of the Block IIR satellites deployed at that time period (Ge et al., 2005).

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JPL IGS ANALYSIS CENTER REPORT, 2003-2004

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1 SUMMARY

JPL contributes two GPS ephemeris products to the IGS (Table 1), both of which include precise estimates of GPS transmitter orbits and clocks. Latency and quality differ between the two, with the JPL final FLINN results being more accurate. The products are available from JPL in both IGS and GIPSY formats via anonymous ftp (ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/jpligsac). Performance for years 2003 and 2004 based on comparisons with the IGS final products is summarized below in Table 1. The values given in Table 1 were generated by taking the RMS of all the weekly (for Final-FLINN) or daily (for Rapid) WRMS values (-orbit and clock) for the JPL contribution in the IGS Rapid/Final Orbit Combination summary files for years 2003 and 2004.

Table 1: Product Quality, 2003 - 2004

Products	Delivery	Orbit	Clock
Final - FLINN	Weekly	**3.4 cm**	**4.3 cm**
Rapid	Daily	**6.1 cm**	**5.6 cm**

2 PROCESS IMPROVEMENTS

Continuous estimation strategy improvements are listed in Table 2. The utilization of 80-stations in the FLINN analysis in April 2003 led to our longest period of 3-cm IGS orbit comparisons (shown in Figure 1-). Our current process improvement emphasis is on the identification of poorly performing stations and the removal of those data from the orbit generation process. This is performed iteratively on each day through an analysis of each station's overall phase and range residuals, during which the poorly performing stations are identified and removed from the subsequent iterations in the orbit estimation.

Table 2: Strategy Updates

Action	Date
USN3 chosen as favored reference clock	09/17/2004
Improved process for identification of poorly performing receivers	mid 2004
Adopted CODE monthly C1-P1 bias values	03/08/2004
Additional outlier removal cycle	02/10/2004
Upgrade analysis software to GIPSY-OASIS 4.0	10/22/2003
Increase FLINN from 60 to 80 sites	04/20/2003
Improved hi-rate clock process	04/01/2003
Create sp3c files	02/16/2003

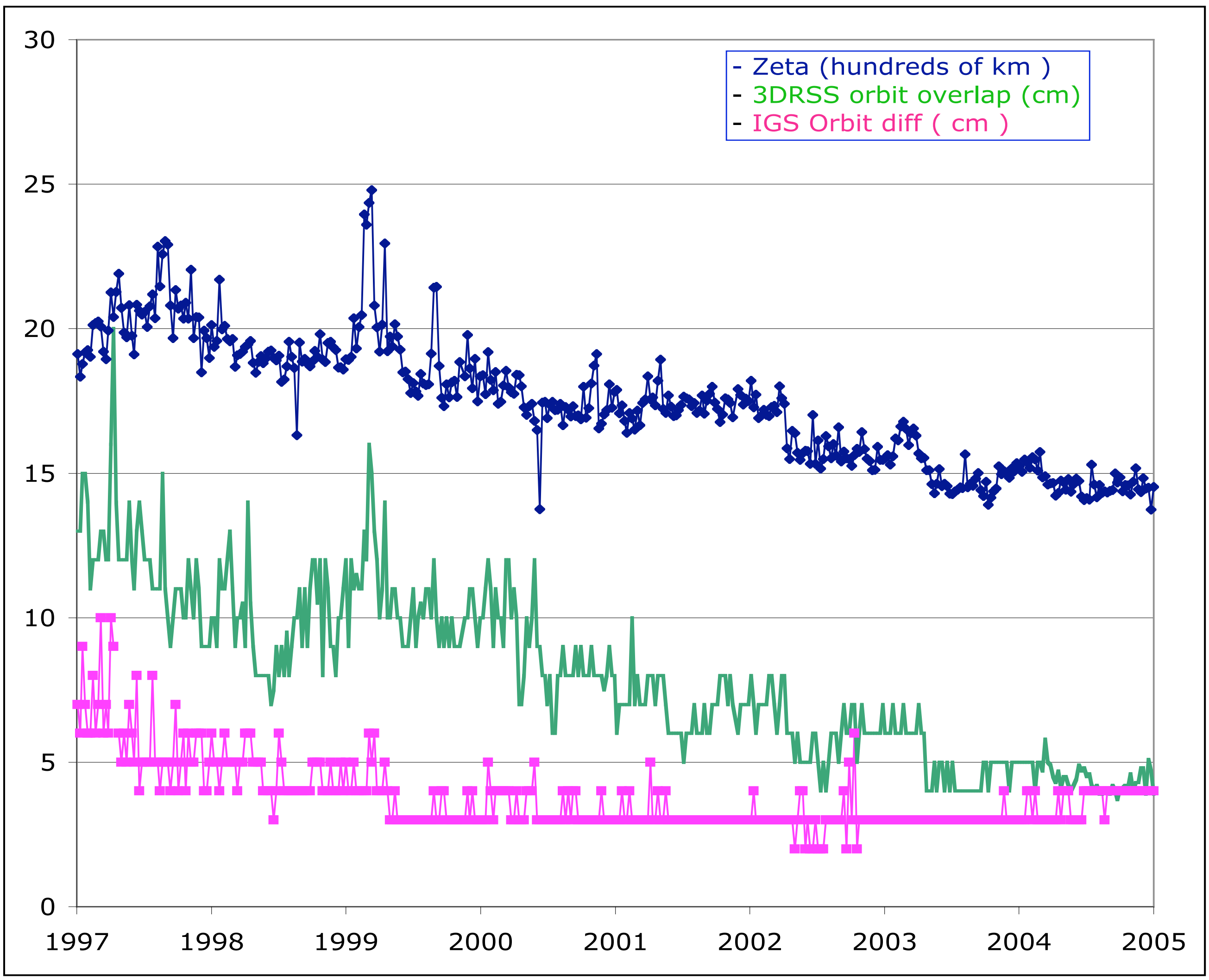

Figure 1: Performance Metrics (2003 – 2004)

Figure 1 shows the three main metrics used for monitoring product quality and performance; (1) Zeta (in blue) in hundreds of km is representative of the global site distribution (zeta is the RMS distance to the nearest analyzed site), (2) three-dimensional orbit overlaps (in green-) from day to day in cm, and (3) one-dimensional IGS orbit comparisons in cm (-shown in pink). Historically, there has been a correlation between global tracking site distribution (zeta) and overall orbit quality.

Precise point positioning with JPL FLINN orbits and clocks is used to estimate positions for hundreds of additional tracking sites around the world. Figure 2 shows the growth of point positioning over time from approximately 20 sites per day in 1991 to more than 700 sites per day in 2004. Post-processing based on these final FLINN products is used to derive time series for the IGS, SCIGN, CORS, NBAR, and PANGA networks. These time series contribute to reference frame determination and provide helpful insight into geophysical processes including global plate motion, post-glacial rebound, seasonal loading, co- and post-seismic deformation due to earthquakes, and interseismic strain accumulation.

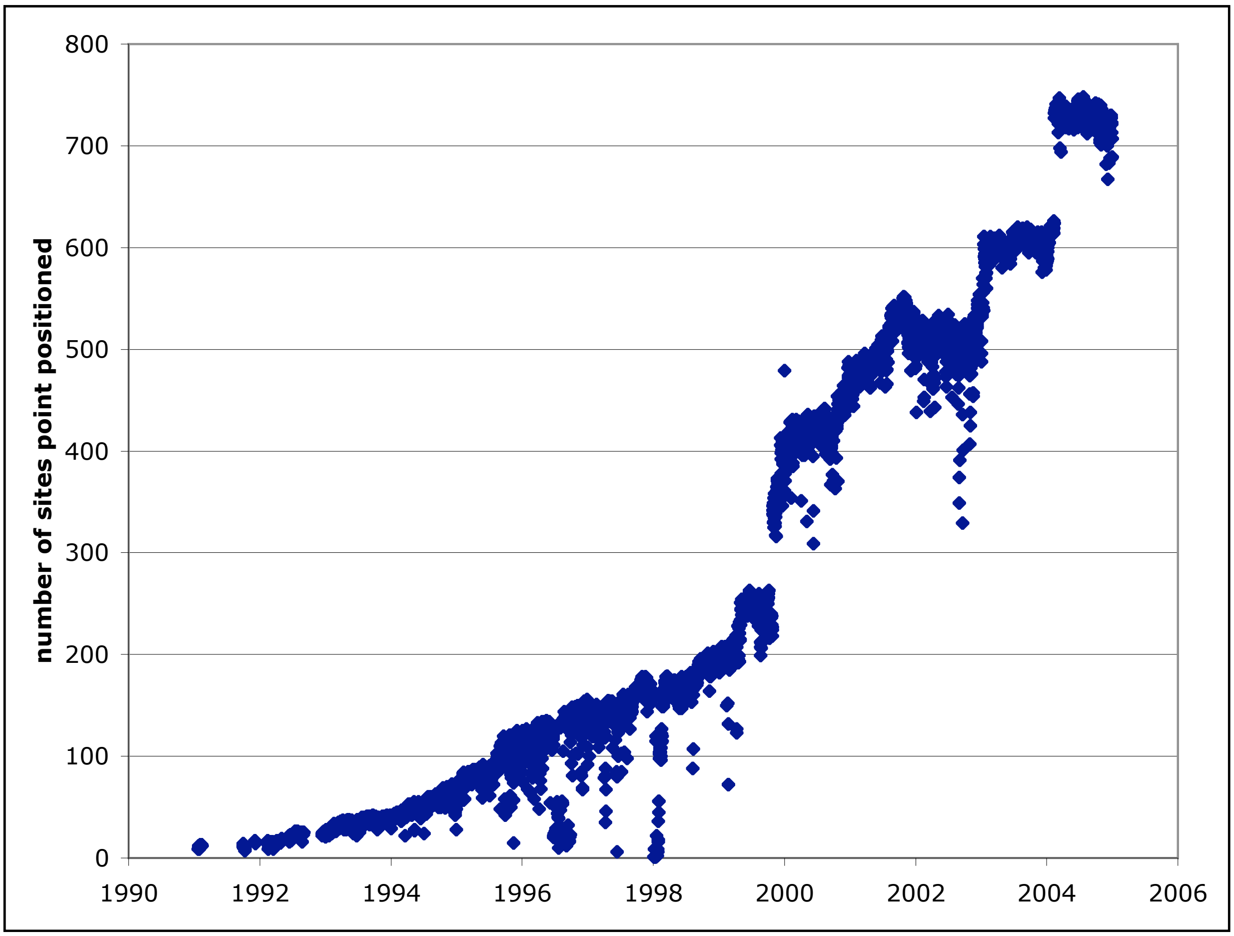

Figure 2: Station Point Positions Per Day

3 PRODUCTS

Various products are made available via ftp and http as listed in Table 3. There are two major orbit and clock products. The JPL Rapid are generally available within 12 hours past end-of-day, while the final FLINN products are posted weekly.

Acknowledgment

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Table 3: Product Files

Rapid Products

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ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/RapidService/orbits
jpl12500.clk.Z
jpl12500.erp
jpl12500.sp3.Z
jpl12500.sp3c.Z
jpl12500_pred.sp3.Z
jpl12500_pred_pc.sp3.Z
2003-12-21.DONE
2003-12-21.PREDICT
2003-12-21.TPNML.Z
2003-12-21.TPNML.predict.Z
2003-12-21.eci.Z
2003-12-21.eci.predict.Z
2003-12-21.eci.predict.edited.Z
2003-12-21.frame
2003-12-21.gps_clocks.Z
2003-12-21.shadow_events.Z
2003-12-21.yaw_rates.Z

Table 3: Product Files (continued)

Final - FLINN Products
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ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/jpligsac/1250
jpl12500.clk.Z
jpl12500.sp3.Z
jpl12500.sp3c.Z
jpl12500.tro.Z
jpl12500.yaw.Z
jpl12507.erp.Z
jpl12507.snx.Z
jpl12507.sum.Z
ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/2003/orbits
2003-12-21.eci.Z
2003-12-21.frame
2003-12-21.shad.Z
2003-12-21.tdpc.Z
2003-12-21_nf.eci.Z
2003-12-21_nf.tdpc.Z
2003-12-21tpeo.nml.Z
2003-12-21tpeo_nf.nml.Z

GPS Orbit and Earth Orientation Parameter Production at NOAA for 2003-2004

National Geodetic Survey
National Ocean Service
National Oceanic and Atmospheric Administration
Silver Spring, MD USA

Spatial References System Division
William G. Kass, Robert L. Dulaney III, Robert B. Leonard Jr.

Geosciences Research Division
Gerald L. Mader, William H. Dillinger, Jim Ray, Jim Rohde, Stephen Hilla

1 Introduction

The GPS orbit and Earth Orientation Parameter (EOP) solutions submitted to the IGS by the National Geodetic Survey (NGS) are a joint effort between the Spatial Reference System Division (SRSD) and the Geosciences Research Division (GRD). The GRD is responsible for the development of the processing software and techniques while the SRSD is responsible for the operational production. SRSD and GRD are both activities within NGS which is part of the National Ocean Service (NOS) of NOAA (National Oceanic and Atmospheric Administration). A detailed description of the techniques and models can be found in the Analysis Strategy Summary located at
http://igscb.jpl.nasa.gov/igscb/center/analysis/noaa.acn

2 Station Network

Figure 1 shows a set of baselines used for forming double differences and for connecting the stations in the tracking network, for a week in late 2004. Starting with GPS week 1294 (24 October 2004) NGS began using a new network scheme which now includes redundant baselines; this was made possible by using a Helmert blocking stategy. Although we increased the number of tracking sites from 70 to 120, the new procedure reduced the computer run time 40 percent. This improved our final orbit comparisons with the IGS by one to two centimeters. The number of sites appears adequate to provide an overall tracking network stability that is relatively insensitive to daily tracking site drop outs within the global network. Included tracking sites are listed in the weekly summary available at the Crustal Dynamics Data Information System (CDDIS) at ftp://cddis.gsfc.nasa.gov/pub/gps/products .

Software Changes

Only a few software enhancements were made during 2003-2004. PAGES/GPSCOM, both developed at NGS, remain the software tools used for orbit production. Starting with GPS week 1224 (June 22, 2003) for the finals, a new set of scripts was implemented which does a least squares fit of all the satellite initial condition parameters (position, velocity, and solar radiation pressure terms) to improve the a priori ephemeris. On January 11, 2004 NGS, along with the other Analysis Centers, switched from the IGS00 reference frame to the new IGS realization of the ITRF2000 reference frame (IGb00). On February 27, 2004, corrections were made to the implementation of the Dehant solid earth tide model in PAGES, and to the pole tide model taken from the IERS 2003 conventions. During the last part of 2004, changes were made to PAGES to allow the use of the new ANTEX files, although these were not used in production until 2005.

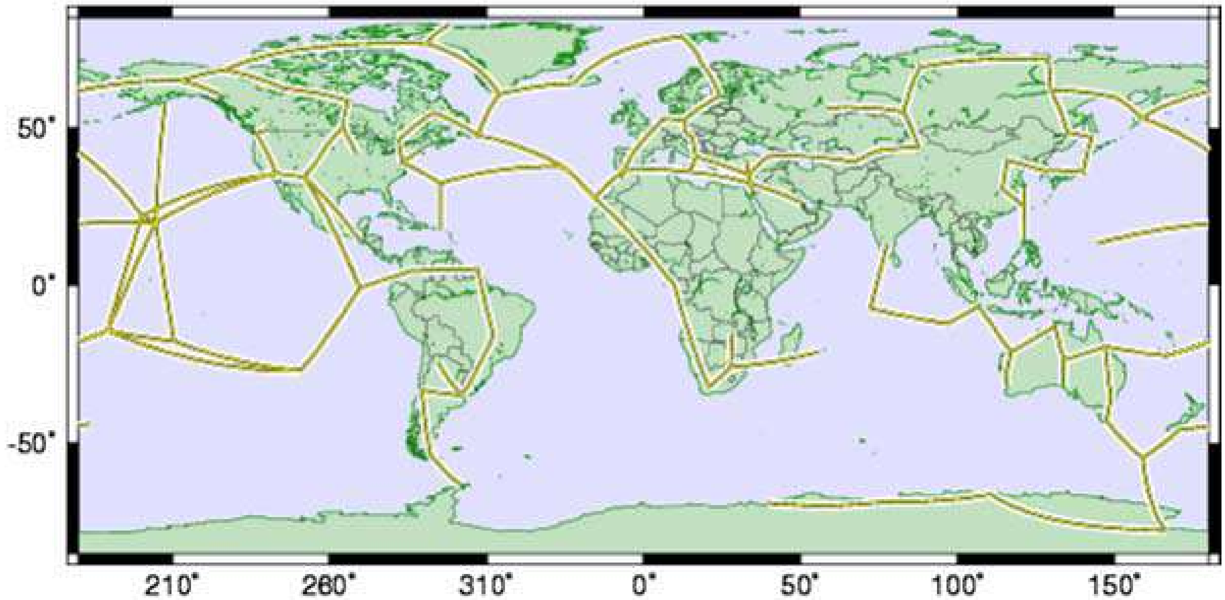

Figure 1

Product Evaluation

The year 2003 began during GPS week 1199 and ended during week 1251. The year 2004 ended during week 1303. Using these GPS week numbers as reference, one can evaluate the NGS products (rapid orbits, final orbits, and earth orientation parameters) using the history plots available at the IGS Analysis Center Coordinator (ACC) website: http://www.gfz-potsdam.de/pb1/igsacc/index_igsacc.html . The history plots for the WRMS of IGS Rapid orbits (smoothed) show that the WRMS for the NGS rapid orbits improved from about 9 centimeters during early 2003 to about 3.5 centimeters during late 2004. The history plots for the WRMS of IGS Final orbits (smoothed) show that the WRMS for the NGS final orbits improved from about 7 centimeters in early 2003 to about 4 centimeters in late 2004. The history plots for the AC Final ERP differences with IGS Finals show that there was a significant decrease in the amount of scatter for the NGS ERPs after week 1294 when NGS went from 70 to 120 stations and began adding in redundant baselines (these cause the many “closed-loops” that appear in Figure 1).

Orbit Products

I. Minimally Constrained Precise GPS Orbit: A consistent minimally constrained weekly solution in the IGb00, epoch 1998.0 reference frame

available - 4 to 10 days from date of observation

recipient – ACC, GeoForschungsZentrum, Potsdam, Germany.
International GNSS Service (via cddis.gsfc.nasa.gov).

accuracy - approximately 2-3 centimeters

II. Rapid GPS Orbit: Up to 70 constrained IGS fiducial tracking sites in the IGb00, epoch 1998.0 reference frame

available - 16 hours from last observation

recipient – ACC, GeoForschungsZentrum, Potsdam, Germany.
International GNSS Service (via cddis.gsfc.nasa.gov).

also at - http://www.ngs.noaa.gov/GPS/NGSorbs/rapid

accuracy - approximately 2-4 centimeters

III. Earth Rotational Parameters: Rapid and precise polar motion values

available - 16 hours from date of last observation

recipient – ACC, GeoForschungsZentrum, Potsdam, Germany.
International GNSS Service (via cddis.gsfc.nasa.gov).

accuracy - approximately 0.25 milli-arcseconds

IV. Troposheric estimates for the zenith path delay

available - 4 to 10 days from date of observation

recipient – ACC, GeoForschungsZentrum, Potsdam, Germany.
International GNSS Service (via cddis.gsfc.nasa.gov).

NRCan IGS Analysis Center Report for 2003-2004

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During years 2003-2004, minor changes were implemented in the computation of the Final, Rapid and Ultra Rapid products in order to conform to IGS standards, improve product quality and increase reliability and robustness. The following pages document the most significant changes to the strategies and software used to generate various products contributed by NRCan to the IGS. CSRS-PPP, a NRCan Web application for GPS positioning using IGS products, is also described.

1. NRCan Final and Rapid Products

During 2003-2004, NRCan continued to estimate Rapid and Final products using JPL's GIPSY-OASIS version 2.6 software as described in ftp://igscb.jpl.nasa.gov/igscb/center/analysis/emr.can. Tables 1a and 1b list several changes made to the NRCan strategy based on IGS recommendations. These Tables also list modifications made to the processing strategy to improve the consistency and reliability of the Rapid and Final solutions.

1.1 Results

During years 2003-2004, the NRCan Rapid products contributed to the IGR combination 94% of the time, and the NRCan Final products did 100% of the time. The NRCan Rapid and Final orbit WRMS with respect to the combined IGS Rapid and Final orbits for the period 2003-2004 can be seen in Figure 1. The only significant improvement in the quality of the NRCan orbits during 2003-2004 was as a result of applying the IGS recommended satellite antenna phase center offsets at the start of GPS week 1216 (April 27, 2003). Table 2 summarizes the changes that were applied to the internal GIPSY satellite antenna phase center offsets. Starting with GPS week 1216, the improvement in consistency between the NRCan and IGS orbits coincides with the application of 5-6 cm corrections to the Block IIR X and Y offsets applied internally by GIPSY, to conform to the IGS conventions. Beginning with GPS week 1263, the reliability of the NRCan Rapid orbits was improved when a pre-processing strategy was implemented to check the quality of data input to the Rapid solution using a Precise Point Positioning (PPP) strategy with the IGU orbits and clocks.

The NRCan Rapid and Final clock RMS with respect to the combined IGS Rapid and Final clocks for the 2003-2004 period can be seen in Figure 2. Improvements were made in the NRCan clock offsets beginning with GPS week 1227. Specifically, improvements were made to the PPP routine used to estimate station clocks once the NRCan global estimation is completed. The PPP strategy fixes the NRCan orbits and clocks from the global solution to augment the number of station clocks processed.

__Table 1a:__ Final/Rapid Processing Strategies Modifications in 2003.

GPS Wk	Date	Modifications
1208	2003-03-02	Adoption of new set of <P1-C1> bias values (v4.0) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1216	2003-04-27	Began applying corrections to internal GIPSY Satellite Antenna Phase Centers to conform to IGS conventions (see Table 2).
1219	2003-05-18	Adoption of new set of <P1-C1> bias values (v4.3) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1227	2003-07-13	Improvement of Rapid/Final station clock estimation using PPP (fixing EMR orbits and clocks) to augment NRCan Rapid/Final station clock solution.
1234	2003-08-31	Re-aligned NRCan Final UT1-UTC value to VLBI derived value (Bulletin A) on day 0 and then resumed NRCan's normal daily estimation procedure for UT1-UTC.
1236	2003-09-16	Re-aligned NRCan Rapid UT1-UTC value to VLBI derived value (Bulletin A) on day 2 and then resumed NRCan's normal daily estimation procedure for UT1-UTC.
1242	2003-10-26	Increased number of stations processed in Rapid solution from 30 to 35.

__Table 1b:__ Final/Rapid Processing Strategies Modifications in 2004.

GPS Wk	Date	Modifications
1253	2004-01-11	Adoption of IGb00 (IGS v2 realization of ITRF 2000) station coordinates and velocities.
1257	2004-02-08	Adoption of new set of <P1-C1> bias values (v4.5) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1263	2004-03-21	Implementation of PPP (fixing IGU orbits and clocks) to validate stations carrier phase and pseudorange observations for Rapid solution. Also began using PPP results to validate reference frame stations prior to constraining in the Rapid solution.
1271	2004-05-16	Adoption of new set of <P1-C1> bias values (v4.6) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1279	2004-07-13	Re-aligned NRCan Rapid UT1-UTC value to VLBI derived value (Bulletin A) on day 2 and then resumed NRCan's normal daily estimation procedure for UT1-UTC.
1281	2004-07-25	Re-aligned NRCan Final UT1-UTC value to VLBI derived value (Bulletin A) on day 0 and then resumed NRCan's normal daily estimation procedure for UT1-UTC.
1284	2004-08-15	Adoption of new set of <P1-C1> bias values (v4.7) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.

1.2 Future Plans

In 2005, NRCan plans to switch from JPL's GIPSY-OASIS v2.6 to GIPSY-OASIS r4 software for both the Rapid and Final products. During this software version update, tests are also planned to investigate the workload required to migrate from the current HP-UX architecture to Linux servers. Other planned efforts in 2005 include the development and implementation of a strategy to estimate high rate (30 second) satellite clock offsets, the alignment of NRCan's Final clocks to ITRF, and the testing of a strategy to utilize absolute station and satellite antenna phase center values as well as their corresponding PCVs in Antex format.

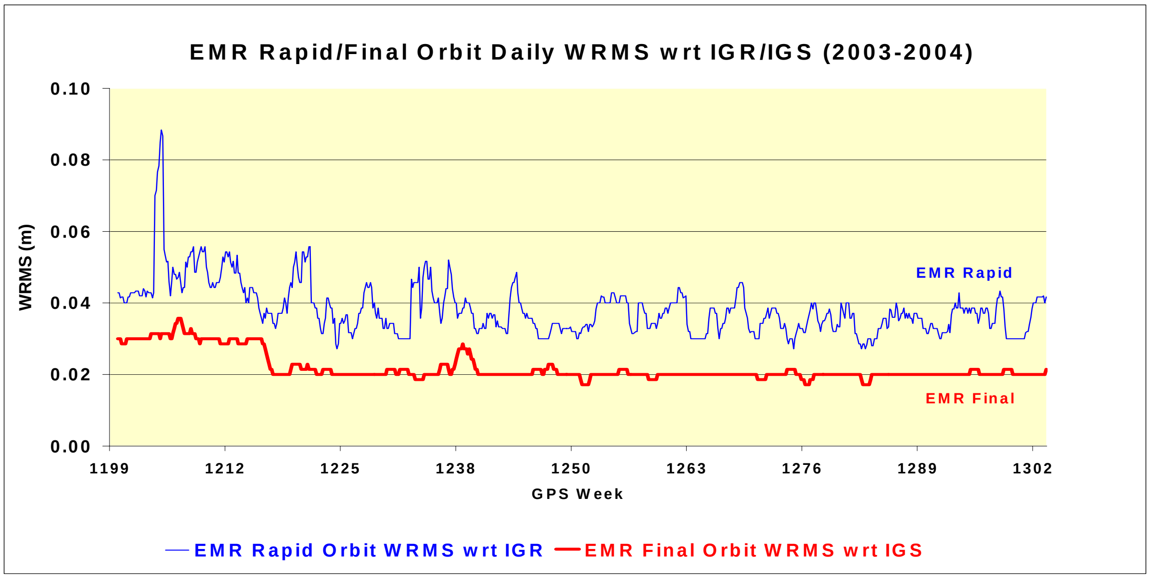

Figure 1: *NRCan Rapid/Final orbit daily RMS wrt IGR/IGS for year 2003-2004.*

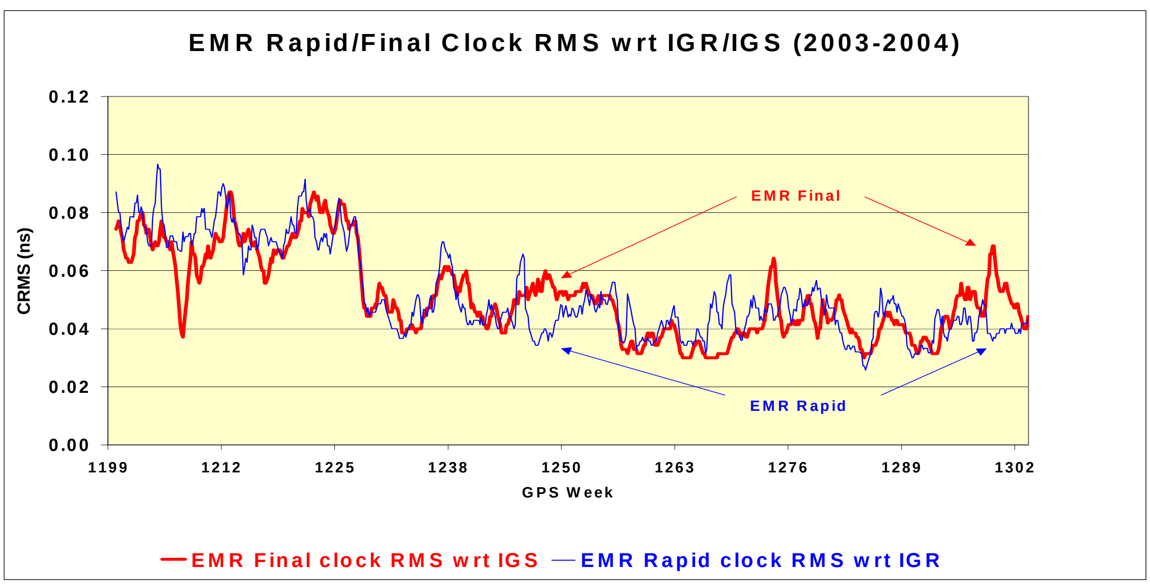

Figure 2: *NRCan Rapid/Final clock daily RMS wrt IGR/IGS for year 2003-2004.*

Table 2: *Satellite Antenna Phase Center Offsets in NRCan Final/Rapid Processing.*

Satellite PC Value	Block II/IIA			Block IIR		
	X(m)	Y(m)	Z(m)	X(m)	Y(m)	Z(m)
GIPSY Internal Value[1]	0.2794	0.000	0.9519	0.058	-0.068	-0.630
IGS Convention	0.2790	0.000	1.0230	0.000	0.000	0.000
Correction to Internal Value Starting GPS Week 1216	0.0000	0.000	0.0711	-0.058	0.068	0.630

2. NRCan Ultra Rapid Products

2.1 Processing Strategy and Changes

During the 2003-2004 period, NRCan continued its development and delivery of Ultra Rapid products (EMU) to IGS using the Bernese v4.2 software [2]. The predicted portion of the orbit also supported computation of real-time wide area GPS Corrections (GPS.C) distributed via geostationary satellite by the Canada-Wide DGPS Service (CDGPS, [3]). Several changes were implemented to our strategy as can be seen in Tables 3a and 3b. By far, the most important modification was the implementation of integer ambiguity resolution, which resulted in appreciable improvement in the quality of our Ultra Rapid orbits and clocks (see section 2.2). Ambiguity resolution is performed on a 6-hr window, which is our standard 3-hr window "expanded" by 3 hours. The additional 3 hours are needed for integer ambiguity resolution and do not significantly delay the orbit/clock estimation, maintaining timely product delivery, a key factor for real-time users. Note that the expanded window is only used for ambiguity resolution and that normal equations are still produced for a 3-hr period. Ambiguity resolution statistics are scrutinized and integer ambiguities are reset to their real values if judged to be suspect.

Table 3a: *Modifications to NRCan Ultra Rapid processing strategy in 2003***.**

GPS Wk	Date	Modifications
1208	2003-03-02	Adoption of new set of <P1-C1> bias values (v4.0) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1217	2003-05-07	Global station summary files now sent to ACC (orbits and troposphere).
1218	2003-05-13	Started using moon shadow events in ORBGEN.
1219	2003-05-18	Adoption of new set of <P1-C1> bias values (v4.3) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1238	2003-10-01	Station geometry for clock estimation improved.
1244	2003-11-13	Use of UT1R for UT1 prediction.

__Table 3b:__ Modifications to NRCan Ultra Rapid processing strategy in 2004.

GPS Wk	Date	Modifications
1252	2004-01-09	Implementation of integer ambiguity resolution.
1253	2004-01-11	Adoption of IGb00 (IGS v2 realization of ITRF 2000) station coordinates and velocities.
1253	2004-01-14	Added PRN22 to processing.
1254	2004-01-18	Ultra Rapid solutions sent to ACC every 6 hours.
1256	2004-02-05	Adoption of new set of <P1-C1> bias values (v4.5) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1262	2004-03-15	Ultra Rapid solutions ftp'd to CDDIS for backup.
1271	2004-05-16	Adoption of new set of <P1-C1> bias values (v4.6) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1279	2004-07-15	Added PRN23 to processing.
1279	2004-07-16	Correction of an error in the computation of the solid Earth tides in the Bernese GPS Software. See http://www.aiub.unibe.ch/download/bswmail/bswmail.0190.
1280	2004-07-19	Implementation of Hatanaka compression software V2.4.2
1284	2004-08-15	Adoption of new set of <P1-C1> bias values (v4.7) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.

2.2 Results

This section compares NRCan Ultra Rapid orbit and clock products (EMU) with respect to the IGS Ultra Rapid (IGU) and Rapid products (IGR). Figure 3 shows the performance of EMU orbits with respect to IGU in terms of orbit RMS, Median RMS and Weighted RMS (WRMS) (including estimated and predicted portions). Spikes can still be seen in the orbit RMS and WRMS plots. They reveal that NRCan (and at times, other ACs) had problems detecting and reporting poorly modeled satellite orbits. Notice however the improvement of the WRMS towards the second half of 2004 mostly due to some improvements in the detection of marginal satellites. Also worth mentioning is the improvement in all 3 RMS plots during 2004 when integer ambiguity resolution started (on 2004-01-09).

Figures 4 and 5 show a comparison of the EMU orbit and clock solutions with respect to the IGS Rapid solutions (IGR). Results are shown after applying a 7-parameter Helmert transformation (orbits) and a clock offset and drift (clocks). Figure 4 shows the 2003-2004 cumulated time series of the 48-hr EMU orbit comparison with respect to IGR. This plot represents the precision users can expect when using a 48-hour EMU orbit. The graphic is split in two portions: 24 hours of estimated (i.e. with real data) and 24 hours of predicted orbits, with each portion divided into 3-hr bins. Figure 5 shows a similar graphic but for EMU clock products. Notice the scale change for the y-axis between the estimated and predicted portions, the latter being generally more difficult with clocks than orbits.

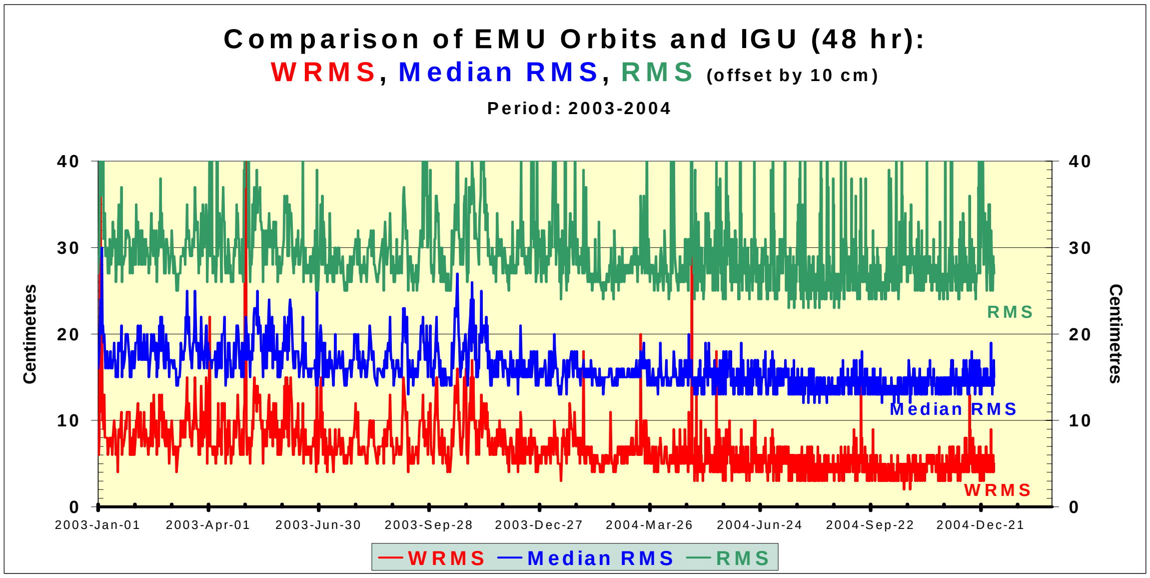

Figure 3: *Comparison of EMU Orbits and IGU for 2003-2004 (48-hour Orbit): **WRMS**, **Median RMS** and **RMS**, each offset by 10 cm.*

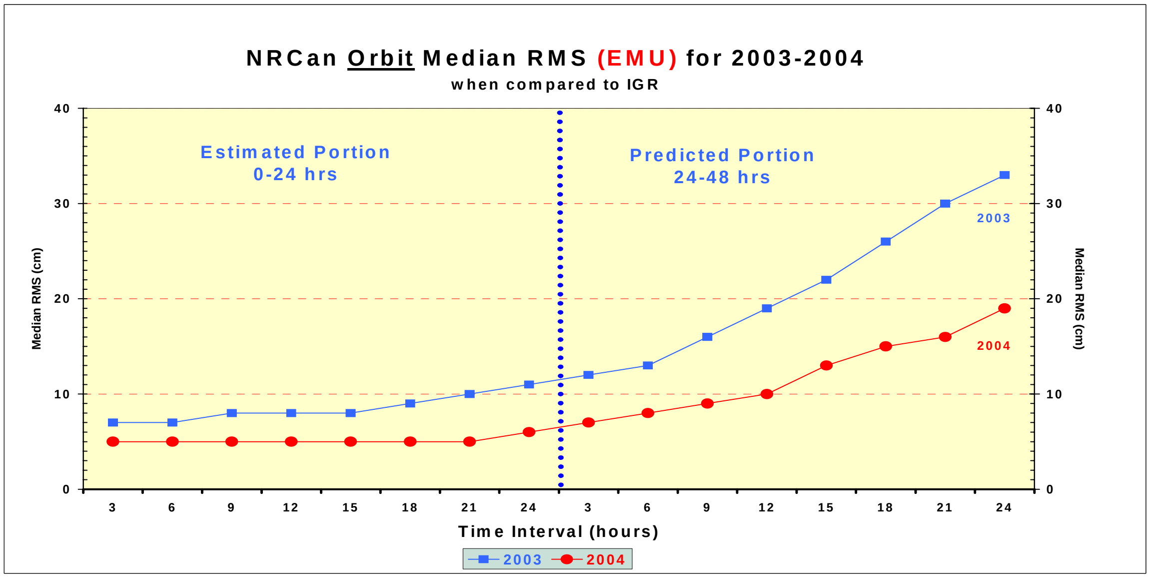

Figure 4: *Comparison of NRCan Ultra Rapid **Orbits** (EMU) with respect to IGS Rapid (IGR) for 2003 and 2004. The graphic is split in two portions: 24-hr for estimated and 24-hr for predicted. Each portion is divided in 3-hr bins.*

The 2004 results for both the orbits and clocks improved greatly compared to the 2003 results. Improvement of the order of ~2-5 cm and up to 14 cm for the estimated and predicted orbit portions, respectively, were seen. For clocks, improvement of ~0.15-0.20 ns for the estimated portion and up to ~1.0 ns could be seen in the predicted part. However, practically no improvement was seen for the shorter 3-hr clock prediction. The improvements seen in 2004 are due mainly to the implementation of integer ambiguity resolution at the beginning of the year.

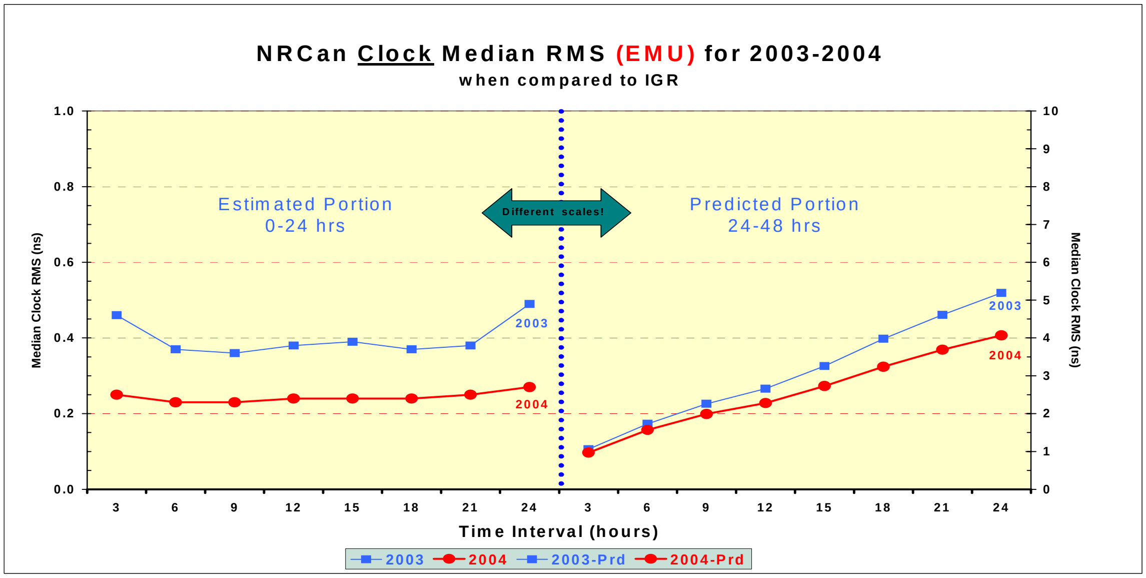

Figure 5: *Comparison of NRCan Ultra Rapid* ***Clocks*** *(EMU) with respect to IGS Rapid (IGR) for 2003 and 2004. The graphic is split in two portions: 24-hr for estimated and 24-hr for predicted. Each portion is divided in 3-hr bins. Note the change of scale between the estimated and predicted portions!*

2.3 Future Plans

Computer resources are scheduled for upgrade in 2005 to provide Ultra Rapid satellite orbits and clocks every hour instead of every 3 hours. At the same time, satellite clock corrections will be estimated every 5- instead of 15-minutes. This would greatly benefit the PPP users. Some time will also be committed to the installation and implementation of the Bernese v5.0 software [4] for our Ultra Rapid products.

3. A new Internet Precise Point Positioning Service based on IGS Products

In October 2003, NRCan introduced an on-line service, CSRS-PPP [5] (http://www.geod.nrcan.gc.ca/ppp_e.php), to provide GPS users with accurate positioning in Canada and abroad through submission of GPS observations from a single receiver, using Internet. The resultant precision is comparable to phase-differential GPS without the need to access or process data collected simultaneously at a base station or to ensure that the coordinates of the base station are properly referenced. CSRS-PPP can process GPS observations from single or dual-frequency GPS receivers operating in static or kinematic mode. To date, almost 80% of the datasets processed were from users operating dual-frequency receivers in static mode. Depending on user equipment, receiver dynamics and duration of the observing session, this application can improve positioning results by a factor of 2 to 100 in comparison to uncorrected point positioning using broadcast GPS orbits.

IGS products are essential to PPP since accurate estimates of the GPS satellite positions and clocks are required. In contrast to DGPS, which relies on field procedures to eliminate or reduce the effect of GPS errors, the PPP approach is based on proper modeling and estimation. While simplifying field logistics, PPP also relieves users from having to deal with uncertainties related to reference frame issues. By connecting directly to IGS satellite positions and clocks that are well defined in a known realization of a global reference frame, end-users can focus on their GPS data collection and application. Although PPP relies on IGS products, it transfers their full benefits to users in a transparent way. With all the models and conventions required to properly use the IGS products, CSRS-PPP can satisfy a large number of end-users and represents an efficient interface to IGS products.

Currently PPP uses most frequently the IGS Rapid and Final clock and orbit products for next day processing. The combined Rapid IGS IONEX products are used as well to process single-frequency data, providing improvement of up to one order of magnitude (from meters to decimeters) in height determination compared to the use of broadcast ionospheric coefficients. Although the estimated portion of the Ultra Rapid IGS products is also used for PPP, the 15-minute sampling of the Ultra Rapid clocks greatly limits its usefulness, especially for kinematic PPP. Unlike the 5-minute sampled Rapid and Final clocks, interpolation is not possible with sufficient precision from Ultra Rapid clocks.

While proper weighting of the GPS orbits and clocks according to their accuracy codes is key to achieving the utmost PPP accuracy, the quality and type of GPS observations processed is also critical. As with DGPS, the highest positioning accuracy is achieved only with geodetic quality, dual frequency GPS receivers operating in a low multipath environment where carrier phase cycle slips are infrequent. Table 4 provides estimates of the precision level that can be achieved with PPP in static and kinematic mode using single and dual frequency GPS receivers. In static mode, precision was evaluated by processing 24-hour datasets and computing the RMS of coordinate differences using the estimated end-of-session positions. Kinematic results were also assessed using GPS data collected with stationary GPS receivers by computing the after-convergence RMS of coordinate differences using the 30-second epoch coordinate estimates. The kinematic statistics shown here represent a best-case scenario since they do not reflect some of the real-world conditions such as the varying multipath environments encountered by a moving receiver.

Table 4: *PPP Performance after convergence – Single and dual frequency – Static and kinematic.*

Receiver	Observation Processed	PPP Mode	Precision (cm)		
			Latitude	Longitude	Height
Dual Frequency	Code & Carrier	Static	1	1	2
		Kinematic	5	4	10
Single Frequency	Code Only (1)	Static	10	10	100
		Kinematic	50	50	150
Single Frequency	Code & Carrier(2)	Static	2	3	4
		Kinematic	25	25	50

Notes (1): Quoted PPP code-only performance is for surveying grade receivers. Performance may vary for other types of receiver

(2): ($\Phi_1/2 + P_1/2$) (not currently available with CSRS-PPP)

Although PPP will likely not achieve the requirements of researchers pushing the accuracy limits of GPS for geodynamics, it remains a valuable tool for a large number of users carrying out GPS positioning. By serving a broader range of end-users, PPP is increasing IGS product usage while connecting end-users into a globally consistent reference frame, insuring consistency of geo-referenced information.

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USNO IGS Associate Analysis Center Annual Report for 2004

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Summary

USNO contributed rapid, ultra-rapid and tropospheric products to the IGS during 2004. The addition of a new workstation to the operations, upgrading to the latest orbit-processing software, applying proven merging techniques, and better modeling have significantly improved the precision of the contributions. The following sections describe the updates to GPS processing at USNO for 2003-2004, the products contributed, the performance of the products for 2003-2004, and future plans.

Updates to Operations

A new computer was added to the Rapid processing operations, providing increased redundancy, fault tolerance and precision. The computer was a Dell PC, loaded with the RedHat Linux operating system. Also, the latest version of GIPSY/OASIS (GOA) orbit processing software, version 4, was installed on the PC. Including the previously existing computers, this resulted in a total of three computers processing Rapid orbits, using GOA software versions 2.5, 2.6 and 4. This three-computer configuration provided greater flexibility in the processing. Each computer could process observation data from different IGS stations, and the individual results merged (orbits, clocks, and Earth orientation parameters), allowing for more stations to contribute to the overall result without having to process all the stations in the same program run.

The merging of individual results used a weighting scheme described in the 2002 report, with weights determined by how well each resulting orbit compares with the available IGS Ultra-Rapid orbits. Often, an imprecise orbit is the result of undetected “bad” observation data (corrupted or otherwise) from a particular station. With each computer processing different station observation data (with some unavoidable overlap), the chance of all 3 computers processing the same corrupted data is reduced. An imprecise orbit for one satellite processed on one computer, due to corrupted station observation data, would be detected when compared against the IGS Ultra-Rapid orbit, and then de-weighted in the merging process.

Each computer attempts to perform a Rapid-product solution twice, before the Rapid submission deadline, for a potential total of six individual solutions. If on one computer, the software fails to produce a solution on one attempt, the impact on the overall merged result is minimal.

Slabinski continued work on his modification of the CODE radiation force model, which was used for the predicted part of the Ultra-Rapid orbits. A satellite's parameter values for use in the model were adjusted, as required, so that the model predictions matched the observed secular perturbations to the GPS orbit. Improvements to this model, along with severe de-weighting of problem satellites, have helped improve the Ultra-Rapid orbit predictions.

Products

Table 1 lists the products that were submitted to the IGS in 2004. For more details regarding the computational strategy see the USNO Analysis Strategy Summary at ftp://igscb.jpl.nasa.gov/igscb/center/analysis/usno.acn.

Table 1. USNO products submitted to the IGS.

File Name	Frequency	Contents
usnwwwwd.sp3	Daily	Estimated GPS satellite positions and clock corrections at 15 minute intervals
usnwwwwd.erp	Daily	Estimated Earth orientation parameters
usnwwwwd.clk	Daily	Estimated satellite and receiver clock corrections at 5 minute intervals
usuwwwwd.sp3	Twice Daily	Estimated GPS satellite positions and clock corrections for 24 hours, and predicted satellite positions and clock corrections for 24 hours, at 15 minute intervals
usuwwwwd.erp	Twice Daily	Estimated and predicted values of Earth orientation parameters
usuwwwwd.zpd	Every 3 Hours	Estimated total zenith tropospheric delay at 30 minute intervals

Performance

Statistics for the USNO rapid orbit and clock solutions are shown in Table 2. The mean and median for the daily values of the weighted root mean square (WRMS), median (MEDI) and clock root mean square (CLK RMS) taken from the IGS Rapid Combinations are given. In addition, the mean and median for the number of receiver clocks per solution, and the number of days that submissions were successfully made are listed. The number of receiver clocks per solution are reckoned from precise-point positioning, used to augment the total number of receiver clocks per rapid solution. Significant improvement has been made since 2002. Year 2002 statistics are provided for comparison.

Statistics for the USNO Ultra-Rapid orbit and clock solutions are shown in Table 3. The mean and median for the daily values of the weighted root mean square (WRMS), median (MEDI) and clock root mean square (CLK RMS) taken from the IGS Ultra-Rapid orbit comparisons are given. In addition, the numbers of successful twice-daily submissions are listed. Note that the satellite orbit and clock statistics refer to the prediction performance, not the determined values derived from observations. Significant improvement, especially in WRMS, has been made since 2002. Year 2002 statistics are provided for comparison.

Table 2. Rapid solution statistics.

Year		Orbit WRMS (cm)	Orbit Median (cm)	Satellite Clock RMS (ns)	# Clocks per solution	# Days submitted
2002	Mean	3.7	3.6	0.075	91.2	358
	Median	4	4	0.07	98	
2003	Mean	2.9	3.0	0.062	107.8	359
	Median	3	3	0.06	108	
2004	Mean	2.6	2.8	0.049	117.2	359
	Median	2	3	0.05	118	

Table 3. Ultra-Rapid solution statistics.

Year		Orbit WRMS (cm)	Orbit Median (cm)	Satellite Clock RMS (ns)	# Twice-daily solutions
2002	Mean	21.1	13.8	5.196	650
	Median	15	13	4.63	
2003	Mean	13.3	12.1	3.966	648
	Median	12	11	2.52	
2004	Mean	13.0	12.1	3.124	647
	Median	12	11	2.90	

Future Work

Toward the end of 2004, USNO initiated steps to acquire the Bernese GPS software, produced by the Astronomical Institute, University of Berne, Switzerland. It is expected that this software will be used for comparison with GIPSY software results, provide research opportunities, and perhaps improve the GPS processing operations.

GOP IGS Analysis Center Report - 2004

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Introduction

The Geodetic observatory Pecný (GOP) of the Research Institute of Geodesy, Topography and Cartography (RIGTC) is located near Prague (Czech Republic). The activity in the field of analyzing GPS data is cooperated with the Department of Advanced Geodesy of the Czech Technical University in Prague. This report explains the initial motivation, consecutive role and the original description of the GOP contribution to the IGS.

Motivation and role

In 1997, GOP was adopted as the EUREF analysis center for ITRF densification in Europe. Since 1999, GOP has been developing near real-time GPS processing for the meteorological applications (Douša, 2001) and participating in the corresponding projects. This activity has driven for developments of the determination precise orbits in near real-time (Douša and Mervart, 2001). The original strategy for a global analysis was developed within 2000-2001 and routinely provided in 2001-2003. Sharing the effort for improving the near real-time orbits motivated GOP in contribution to the IGS. In the beginning of 2004, GOP was adopted as the IGS analysis center without further intention to contribute to the other IGS core products – weekly finals, daily rapids.

GOP products

Since January 2004, GOP has been officially contributing to the sub-daily IGS product delivering the ultra-rapid GPS satellite ephemerides and the Earth orientation parameters and previously (from February 2003) producing the near real-time global tropospheric zenith delays updated every 3 hours. Since 1997, GOP has been delivering the coordinate solution of the regional network in SINEX format to the European IGS RNAAC. All the contributions, other GOP products (e.g. routine regional GPS troposphere product) and data services are accessible on the web (www.pecny.cz/gop) or through GOP data center (ftp.pecny.cz/LDC). The products are provided applying the Bernese GPS software (Hugentobler et al, 2001).

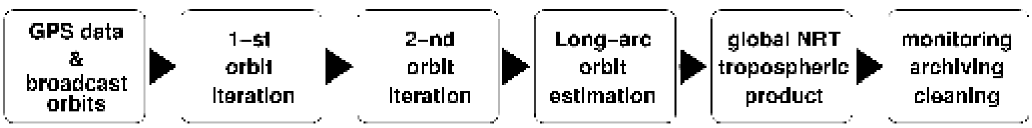

Fig. 1: Sequential processing blocks. Analysis in each step was possibly parallelized.

Processing scheme for ultra-rapids

Already in 2000, GOP started to develop a sub-daily orbit product. The system was designed as much as robust and extremely efficient potentially used with the hourly update. The task was achieved applying combination technique for the short-interval normal equations (6 hours). Because the product is updated every 3 hours, only half of the pre-processing batch is overlapped in contrast to the sliding window processing technique.

No other a priori information is necessary except the concatenated broadcast messages and rapid EOP predictions. The processing of global network consists of the main sequential blocks, as shown in Fig.1, but whenever possible the steps inside the blocks are speeded up applying the parallel approach (e.g. clustering solutions, baseline-by-baseline mode processing etc).

The daily global solution is available at the end of each sequential block. The a priori (broadcast) orbits are iteratively improved based on 24-hour solutions and combined into 3-day global solution for the orbit determination. Afterwards, the global troposphere parameters are derived using already fixed satellite and station positions.
Modified Bernese GPS software version 4.2 was applied in the beginning, while beta version 5.0 replaced it later in 2001. All routines are controlled by the Bernese Processing Engine supported by a system of perl scripts developed in GOP. The processing is based on double-difference observations.

Network and data

The network for GOP global analysis consists of about 60 global stations with hourly data. Only broadcast messages and hourly data are used for the analysis. Concatenation of last six hours is applied on hourly RINEX files, than six-hour batches are pre-processed and later used in the stacking procedure. Since the quality of the results is strongly dependent on the data flow, the file downloads are managed through the specialized GOP data center.

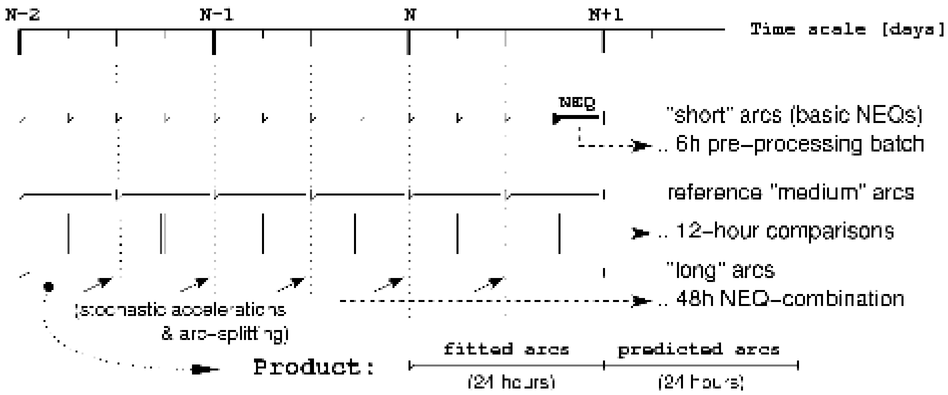

Fig. 2: Chart of the long-arc orbit combination procedure

Pre-processing strategy

Two iterative steps are performed during the pre-processing for the higher solution stability. Both steps contain the standard approach for analyzing the double-difference: a) a single point positioning with code measurements for synchronization of the receiver clocks; b) creating single-difference observations (the baselines are mostly generated with respect to the regional clusters and maximizing the number of observations); c) cleaning the double-differences (cycle slip detection, ambiguity setting, etc.) and d) rejecting the outliers when site/satellite quality checking is applied in the limited iterative loop. The single differences are stored in the files, while the double-differences are temporarily created only during the least-square adjustments.
Ambiguities are currently not resolved (i.e. estimated as a real numbers) – they are always pre-eliminated before saving the normal equations.
The details on models applied are described in the analysis center log available at the IGS CB.
Improved a priori daily orbits together with saved normal equations are the products of both pre-processing steps. The normal equations are then used in all other relevant combinations during the next 72 hours.

Combination for the final orbits

The final orbit product is available every 3 hours and it is based on the procedure combining 6-hour normal equations into a global 3-day solution, Fig 2. The process is performed iteratively for tuning the appropriate orbit parameterization. Such orbit arc (over 3 days) cannot be always modeled with a single set of the parameters (6 Keplerian and 9 additional radiation pressure parameters – some of them tightly constrained). The long-arc can be split into more pieces (e.g. due to manoeuvres) or additional stochastic pulses can be set up to model the external forces on the satellite motion. The latter are expressed as the small velocity changes at the arc boundaries when stacking consequent 6-hour normal equations.

The final set of the orbital parameters is derived from the iterative recombination procedure based on the normal equations over last 3 days. The iterations are controlled comparing the 3-day orbits to all the corresponding medium-arcs of 12-hour solutions within their intervals of validity. Medium-arcs (covering approximately one satellite revolution) are generated only once from every two consecutive normal equations applying a single set of orbital parameters. The medium-arcs are saved in the files over the upcoming three days. The residuals from the comparisons are analyzed per each satellite and each 12-hour segment and the recommendations are generated for the next phase of the processing. If any orbit of a given satellite cannot be represented by the original set of the parameters, two actions may take place:

- introducing three stochastic (dynamic) parameters in addition to the original set;
- splitting the long-arc with new set of parameters.

The above actions are furthermore limited for:

- splitting during the last 24 hours;
- any segment has to be a multiple of 12 hours at least;
- in case of the large residuals, the single action is allowed only.

The stochastic parameters estimating small velocity changes in radial and along-track components once per revolution are loosely constrained, while the out-of-plane component velocity changes are constrained tightly. The whole process is mostly iterated two or three times.

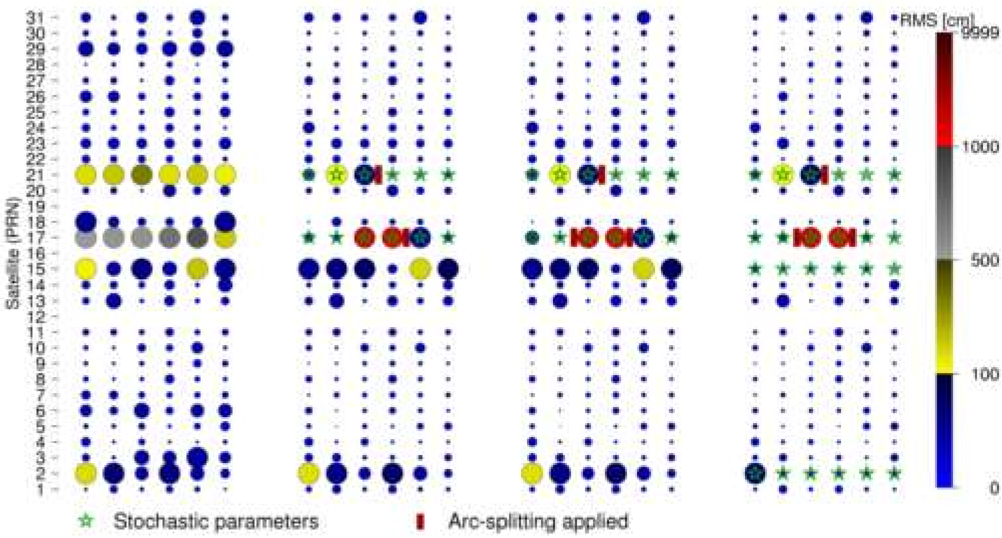

Fig. 3: Example of handling the orbital parameters in the final long-arc determination.

Figure 3 shows an example of the iterative combination technique. Each vertical group of six columns represents a single iteration with residual evaluation for six 12-hour periods. The final iteration set up additional stochastic parameters for 4 satellites (PRN 2, 15, 17, 21) and two long-arc orbits (PRN 17 and 21) were split into 2 or 3 independent segments. The orbit modeling was significantly improved especially within the last day, i.e. the interval, which is used for the official product extraction and prediction.

Robustness and efficiency

The robustness of the solution is achieved through the many control iterative procedures, a self-initializing mechanism and finally, with an independency on external information (satellite manoeuvres, precise a priori orbit positions or other supporting products).
The high efficiency of the solution is possible due to a low-level redundancy in the processing. The redundancy remains only when the product is updated less than every six hours. Actually, GOP has redundancy in pre-processing 3-hour data, which is exploited for the internal consistency measure of the solution. Further reduction of the processing time could be achieved using more precise a priori orbits and avoiding two iterations for the data pre-processing. We protect the current iterative system in favor of its higher robustness.

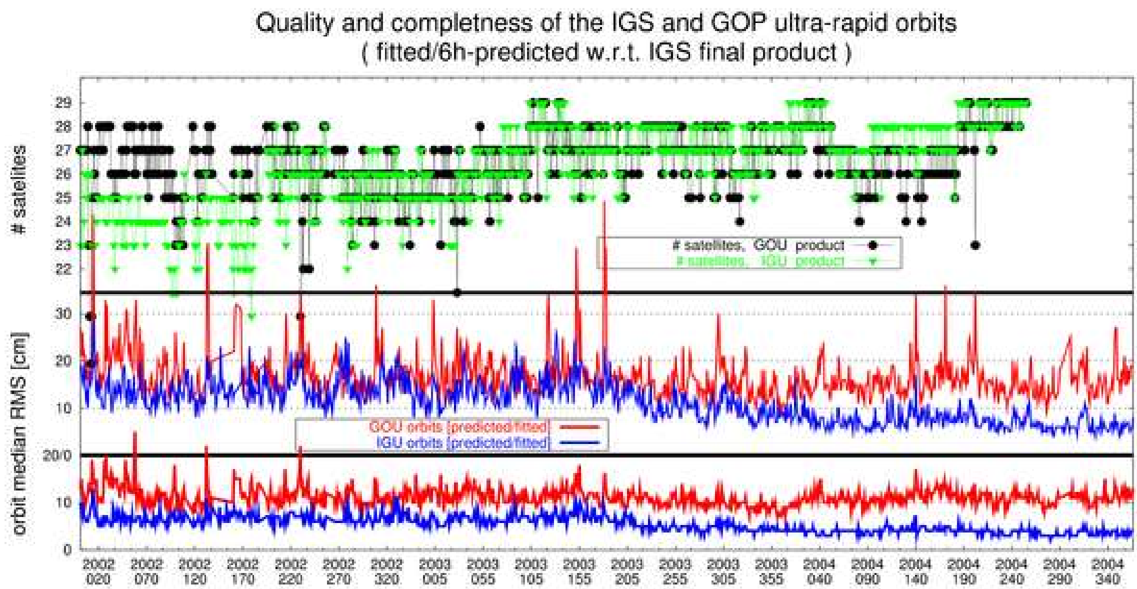

Fig. 4: Evaluation of GOP and IGS ultra-rapid orbits from period 2002-2003.

Orbit evaluation and monitoring

The quality monitoring system is an integral part of our global near real-time analysis. The results are evaluated during the internal checking between consecutive 3-hour orbit updates. Resulted characteristics from the last comparisons are applied for generating the accuracy code for the product in SP3 format. This strategy is not perfect and will be revised in the future.
The quality of the orbits is also monitored by the comparisons to all IGS products in backward. The evaluation is applied only for the last solution of each day (we assume the quality is independent on the hour of day) and the statistics are archived. The differences between GOP and IGS final orbits are at the level of 10-12cm (median RMS) for the fitted portions and bellow

20cm for the 12-hour predicted portion, see Douša (2004) and Fig 4. The figure additionally shows the number of satellites included in both – GOP and IGS – ultra-rapid products.
The evaluation of the orbits has started already in 2002 and because there was no change in the strategy, the long-term characteristics of the product are visible. It is clear, that the GOP contribution to the IGS ultra-rapid product could be significantly larger in 2002 than in 2004 and there is a room for the improvements.

Future developments

Implementation of new Bernese Processing Engine (BPE) and the official Bernese V5.0 is scheduled during 2005. The stabilization of the routine processing especially in the parallel run is anticipated. The development of the better accuracy code is desirable for the product. Appropriate ambiguity resolution would improve significantly the orbit determination. Any missing satellite orbit in the initial normal equations actually causes the satellite missing also in the final product - this occasional technical deficiency should be avoided as well. Appropriate weighting, rather than excluding, should be preferred for any maneuvered/problematic satellite in the future. When having enough CPU for satellite clock estimation, the PPP processing could provide an excellent evaluation and integrity monitoring.

Acknowledgements
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Reference Frame Working Group Technical Report 2003-2004

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Abstract

Natural Resources Canada's (NRCan) Geodetic Survey Division (GSD), on behalf of the International GPS Service (IGS) and its Reference Frame Working Group, combines a consistent set of station positions, velocities, Earth Rotation Parameters (ERP) and apparent geocenter to produce the IGS official station position/ERP solutions in the Software Independent Exchange (SINEX) format. The weekly combination includes solutions from the IGS Analysis Centers (AC), while the Global Networks Associate Analysis Centers (GNAAC) provide quality control.

The weekly AC solutions include estimates of weekly station positions and daily ERPs. At the beginning of 2003, the ACs were processing weekly data from between 40 and 155 stations, at the end of 2004 they were processing between 50 and 180 stations. They also provide separately, satellite orbit and clock estimates as part of their daily products, which are independently but consistently combined by the IGS AC Coordinator to produce the IGS orbit/clock products. The weekly combined stations positions are also accumulated in a cumulative solution containing estimated station positions and velocities at a reference epoch.

Year 2003-2004 activities also included a review of the original IGS realization of ITRF2000 "IGS00". The main objective was to improve the stability of the realization by increasing the number and quality of reference frame stations position/velocity estimates. Key criterions for existing reference frame stations as well as potential new stations were reviewed. About 200 stations were reviewed and 99 were retained. As was experienced with earlier realizations of ITRF, the number of reference frame stations contributing to the realization decreased at a rate of ~5% per year. There are two main causes: 1) not enough data available or 2) discontinuity in station position time series. The effect of the constraints on the contributing AC weekly solutions was also verified and found to be generally negligible. In preparation for the expected call for participation for the upcoming ITRF2004, reanalysis of the combined SINEX products was undertaken with emphasis on the older products. An inventory of the station position time series discontinuities was also prepared.

Introduction

Station positions and velocities, Earth Rotation Parameters (ERP) and apparent geocenter products are combined within the Reference Frame Working Group (RFWG) (Kouba et. al., 1998). These products also influence the combination of the GPS satellite orbit and clock products. Since 2000-02-27 (GPS week 1051), the AC coordinator aligns the orbit products to the IGS weekly SINEX combined solution, thus ensuring IGS product consistency. The contributing Analysis Centers (ACs) and Global Network Associate Analysis Centers (GNAACs) are listed in

Table 1. The weekly SINEX combination is available within 12 days (Thursday) after the end of each GPS week. The daily ERPs are included in the weekly SINEX combination along with the weekly station positions. The combination uses all the available covariance information.

The IGS realization of ITRF is accomplished with a subset of stations of the IGS network. For the original IGS realization of ITRF2000 “IGS00”, which became official on 2001-02-12 (GPS week 1143), 54 high quality stations were selected. A second realization of ITRF2000 including 99 stations became official on 2004-01-11 (GPS week 1253).

IGS Analysis Centers (AC)	
CODE	Center for Orbit Determination in Europe, AIUB, Switzerland
ESOC	European Space Operations Center, ESA, Germany
GFZ	GeoForschungsZentrum, Germany
JPL	Jet Propulsion Laboratory, USA
MIT	Massachusetts Institute of Technology
NOAA	National Oceanic and Atmospheric Administration / NGS, USA
NRCan	Natural Resources Canada, Canada
SIO	Scripps Institution of Oceanography, USA
IGS Global Network Associate Analysis Centers (GNAAC)	
NCL	University of Newcastle-upon-Tyne
MIT	Massachusetts Institute of Technology

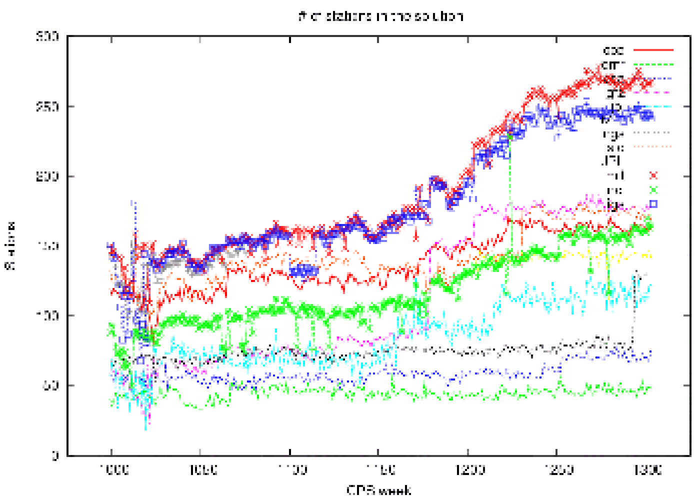
IGS Analysis and Associate Analysis Centers
Table 1

Products

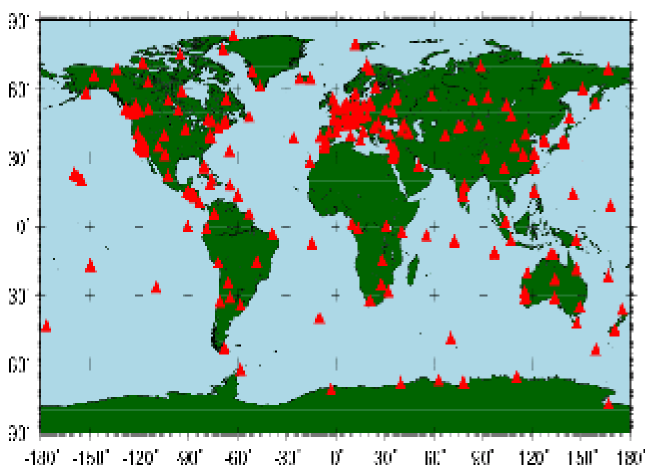
The station positions and ERPs are provided explicitly and the apparent geocenter is by convention, implicitly at the origin. In the analysis, it is made explicit. The AC SINEX solutions are combined using the least-squares technique. All the available covariance information between the station positions, ERPs and apparent geocenter within each AC solution are used. Since 1999-06-06 (GPS week 1013) the weekly combination includes daily ERPs (pole position and rate, calibrated length of day). Since 1999-02-28 (GPS week 0999) weekly apparent geocenter are estimated. The cumulative combination is updated every week with the latest weekly combination. The alignment of the weekly and cumulative solutions is done using a set of reference frame stations.

Stations

In years 2003–2004 (GPS weeks 1199-1303), the number of stations continued to increase. Figure 1 shows the evolution of the number of stations used in the ACs, GNAACs and IGS weekly solutions. The number of stations used by the ACs ranges from about 40 to over 170 stations. In the IGS weekly combined solution the number of stations went from about 190 to about 250, so on average about one new station every 2 weeks. At the end of 2004, there were 278 stations in the cumulative solution. Figure 2 shows their distribution at the end of 2004. New stations in the weekly solutions are not available in the cumulative solution until the velocity estimate has converged to reasonable values. NNR-NUVEL1-A is used to verify the velocity estimates. For continuously observing and processed stations, the time necessary for velocity estimates to converge varies from a few months to about 2 years. The estimates are reassessed 3-4



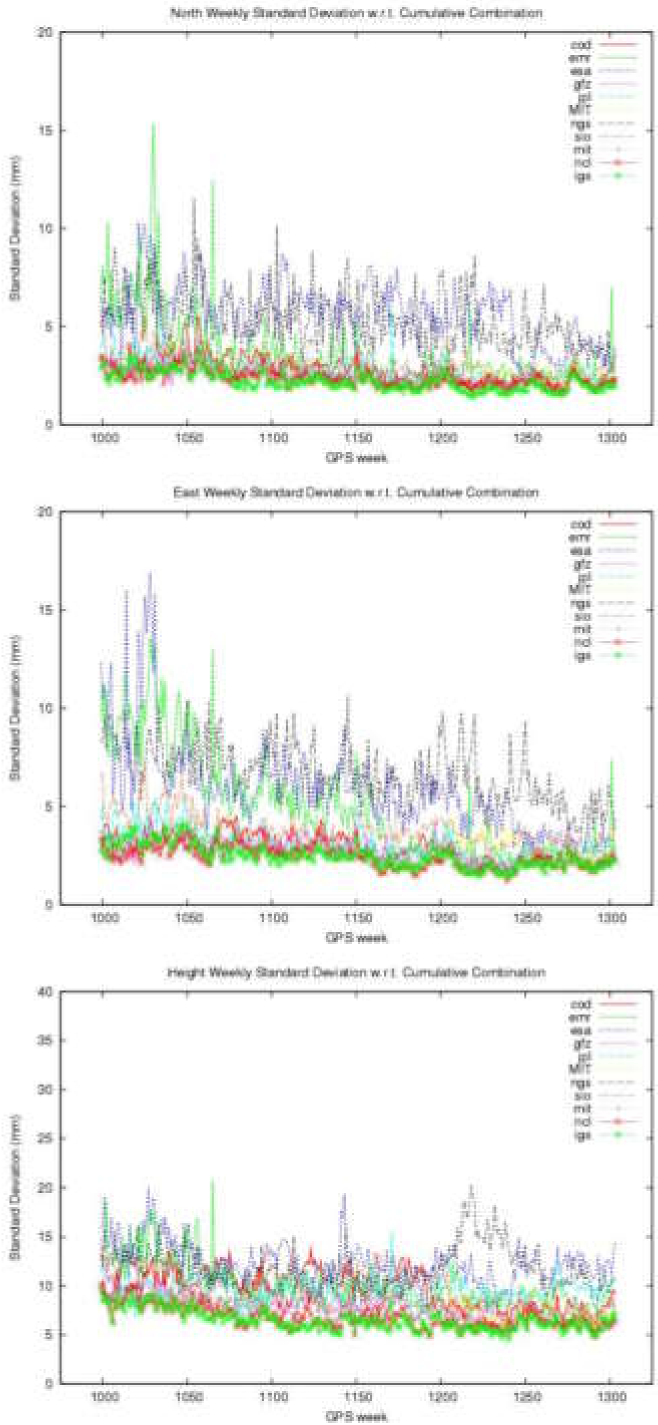
Stations included in the AC/GNAAC/IGS weekly solutions (Wk 0999 – 1303)
Figure 1



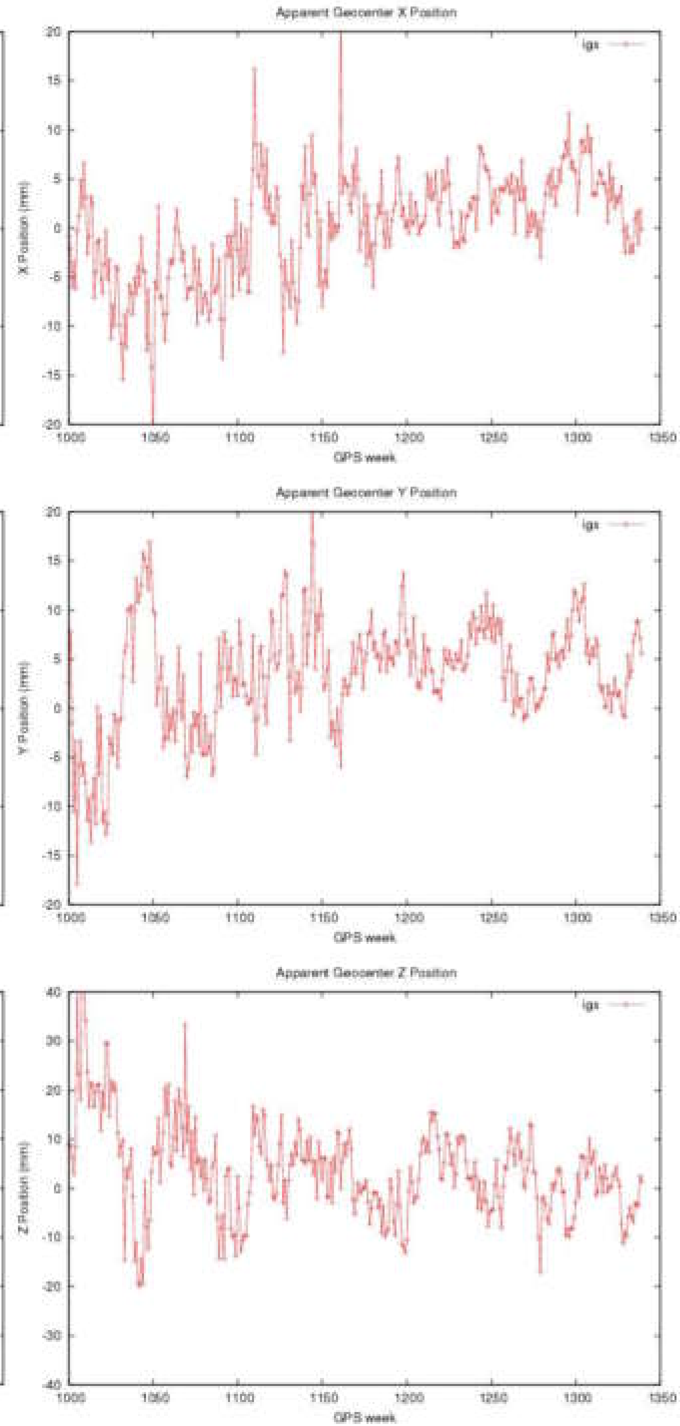
Stations in the IGS cumulative solution at the end of 2004
Figure 2

times a year. The distribution has improved over the last 2 years with the addition of 50 new stations. North America and specially Europe have always had a more concentrated network.

Along with the increased station density, a gradual improvement in the consistency between the IGS weekly and the cumulative solution can be observed. Standard deviations improved from about (2.4, 2.5, 7.0) mm at the beginning of 2003 to (2.0, 2.2 and 6.5) mm at the end of 2004 in the north, east and height components respectively. Figure 3 shows this gradual improvement of the standard deviation of the weekly station position residuals for the ACs, GNAACs and IGS with respect to the IGS cumulative solution. Gradual improvement is apparent especially in the height component. The bandwidth of the standard deviations is also decreasing, indicating an improving consistency between the various solutions. Older statistics also show that the gradual improvement process is continuing. The statistics tend to be worse in winter (December-March) (Ray et al. 2005). Station performance in winter is affected by snow accumulation on the antennas. The effect on a station position can reach several centimeters in the height component.



North, East and Height standard deviation of the stations position residuals of the ACs, GNAACs and IGS weekly solutions and the IGS cumulative solution.
Figure 3



Apparent (X,Y,Z) Geocenter position (mm)
Figure 4

The official IGS weekly and cumulative solutions are subsets of complete solutions containing all the stations provided by the ACs. The complete cumulative solution included about 480 stations at the end of 2004. About 200 stations were not made available in the official cumulative solution for the following reasons:

- missing necessary information (DOME#, log, etc),
- unreliable velocity estimate,
- region is already well covered.

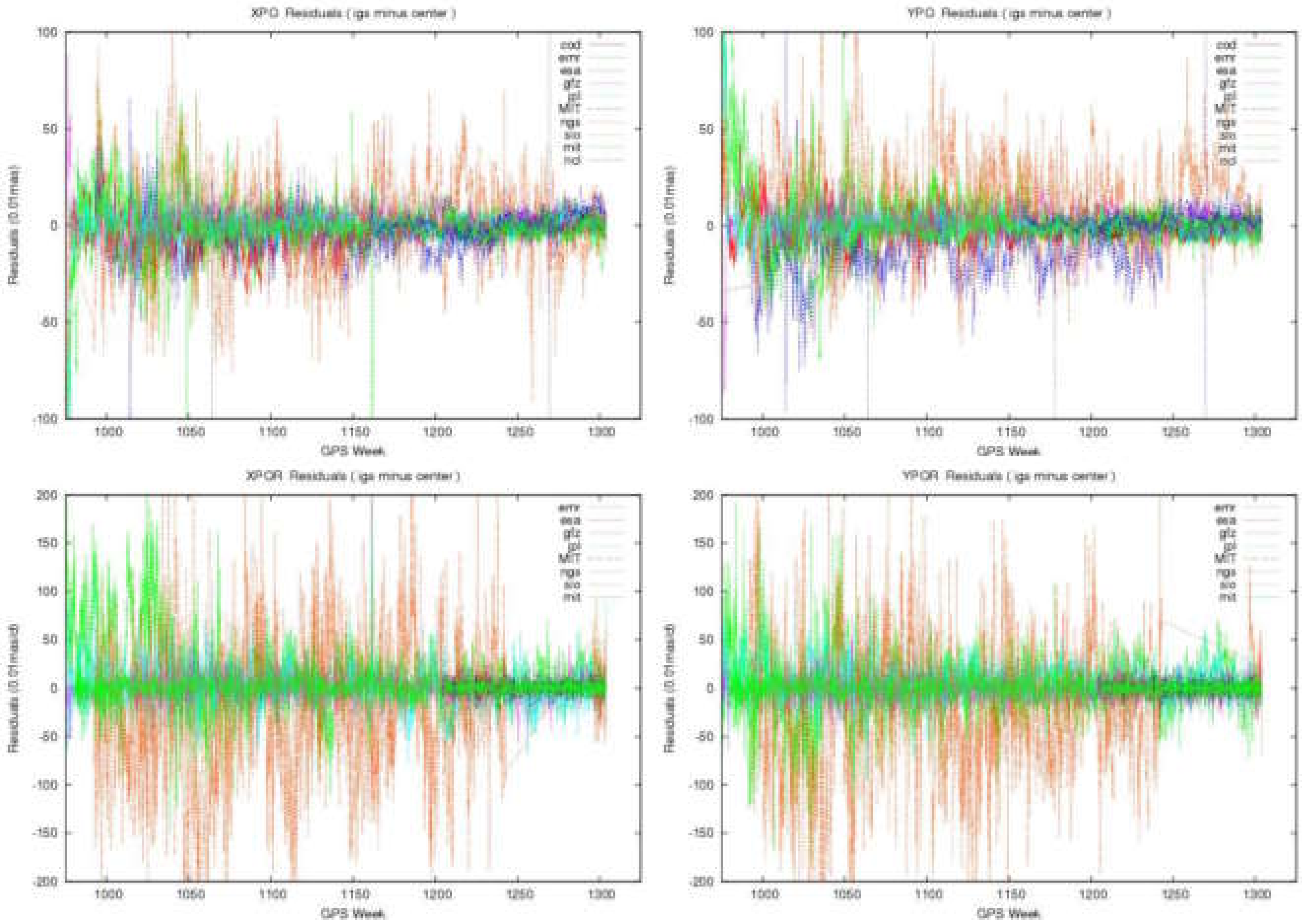
It is convenient to have two cumulative solutions as described above, because when a station is added to the official solution there is no need to reprocess the time series. The removal of stations with unreliable velocity estimates became necessary, because the users almost always assume the available velocity to be accurate. They seldom check the stations position time series or the formal error; so, some quality control became necessary. The number of stations not released in the official weekly solution is usually less than 20, and mainly because necessary information is missing (DOME#, log, etc). Releasing as many stations as possible is consistent with perceived user preferences.

Apparent Geocenter

The combined apparent geocenter estimates does not rely on the estimated translation components of the similarity transformations. It is estimated with the combination of the station positions and the ERPs, adding 3 parameters to explicitly define the origin as the geocenter within each unconstrained AC solution. A one-meter constraint is also imposed on each explicit geocenter component of the augmented systems to avoid singularity in position. This approach allows the use of all the variance/covariance information available in the AC SINEX files. The geocenter estimates are currently with respect to ITRF2000, which used SLR to determine the origin. Since GPS didn't contribute to ITRF2000 origin definition, those two geocenter realizations are independent. In Figure 4, the time series shows the estimates for the combined weekly apparent geocenter in the X, Y and Z directions. The formal uncertainty for the combined weekly geocenter was about 4.5 mm for the X and Y components and 6.5 mm for the Z component at the beginning of 2003 and down to 3.5 mm and 5mm at the end of 2004. The formal uncertainties were 6 mm and 10mm respectively at the beginning of the pilot project on 1999-02-28 (GPS week 0999). For years 2003 and 2004 there is an average bias of (3, 5, 2) mm (X, Y, Z), the slope for that period is (2, 0.5, -4) mm/y. If we consider the entire period, the bias and slope are (-0.5, 3.5, 4) mm and (2, 1.5, -2) mm/y. Biases at the initial epoch are not statistically significant (3 sigmas), but the drifts are. Earlier analysis on part of this data did indicate the presence of an annual period of about 5mm for the X and Y components and about 10mm for the Z component. A semi-annual term could also be detected, although it was smaller (2 and 3mm respectively).

Earth Rotation Parameters

The ACs in their weekly SINEX contribution provide the daily ERPs. The daily ERPs include the pole position, pole rates, LOD and UT. By convention, the estimates are at the middle of each day. The UT parameters are not combined at this time. The AC estimated LODs are calibrated before they are combined using the procedure described in Mireault, et al. (1999). The best AC pole positions and rates are consistent with the IGS combined at the 0.05-0.10mas (0.10–0.20mas/d), while the calibrated LOD are consistent at 20-30μs. Figure 5 shows the daily residuals time series for the X and Y pole (top) and their rates (bottom) between the IGS

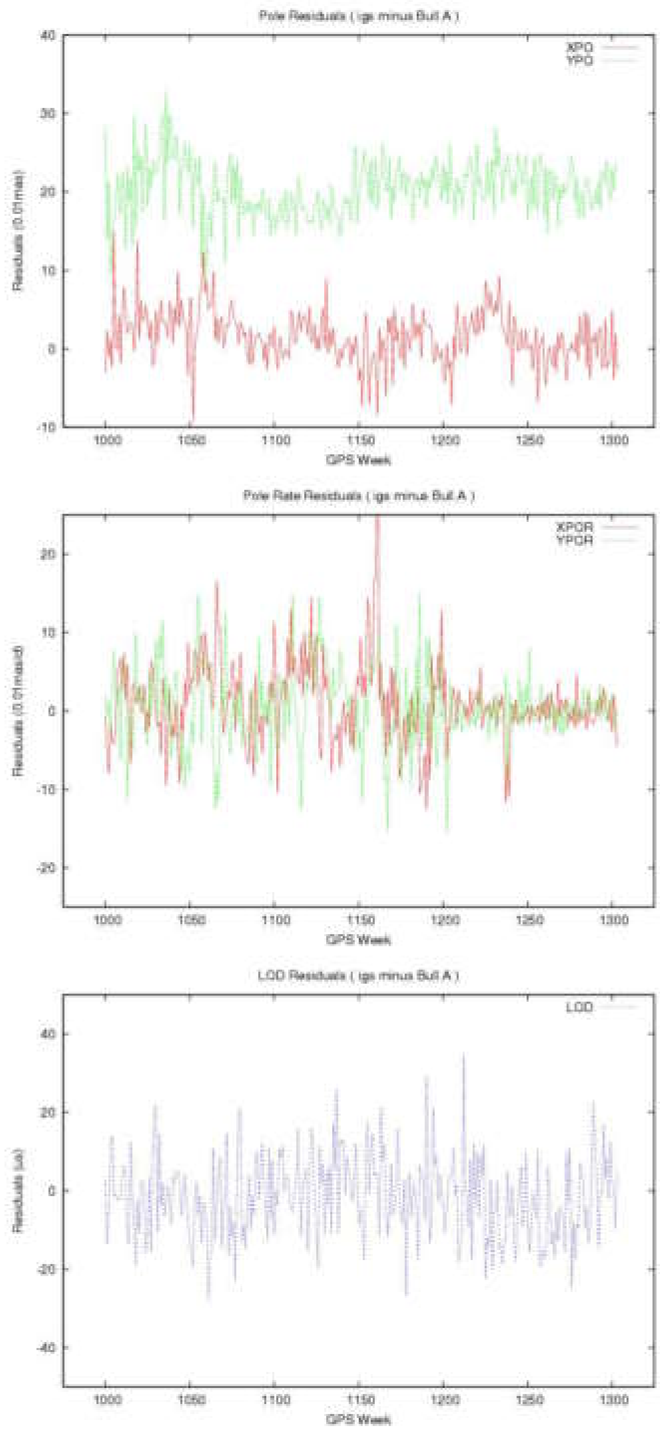


AC & GNAAC daily pole position and rate residuals with respect to the IGS weekly combination

Figure 5

combined solution and the AC/GNAAC. Similarly to the gradual improvement observed with the station positions, the consistency of pole position and pole rate is also improving. The RMS of the residual pole position (and rate) went from about 0.15mas (0.40mas/d) in 1999 to about 0.05mas (0.15mas/d) at the end of 2004. Figure 6 shows the daily difference between the IGS combined solution and Bulletin A. Note that the IGS combined solution and the Bulletin A are not independent, since the AC solutions contribute significantly to Bulletin A. In pole position, the long-term average difference is 0.02mas ±0.04mas and 0.20mas ±0.04mas in X and Y pole position respectively. Recent data confirms this long-term average (0.00mas ±0.03mas and 0.20mas ±0.03mas). Small seasonal fluctuations are also present in the X pole position. For the pole rate parameters, the agreement has improved significantly at the beginning of 2003, when the RMS in X & Y rates went from about 0.06 mas/d to about 0.03 mas/d. There is no significant bias between the X and Y pole rate series. The average long term LOD difference is unbiased. This is expected since as mentioned above, the ACs LODs are calibrated to Bulletin A. Comparison with recent data (2004) suggests a very small bias of –4μs between the two series. The noise level is fairly constant at 10μs. Note that the Bulletin A daily estimates were linearly interpolated to match the corresponding epochs of the IGS combined values.

Review of the "IGS00" realization of ITRF2000



X&Y Pole/Pole Rate and LOD differences between the IGS combined and Bulletin A
Figure 6

The use of the "IGS00" realization of ITRF2000 (Altamimi et al. 2002) started on 2001-02-12 (GPS week 1143). It included 54 globally distributed stations (Figure 7). Since then, the number of usable stations for the reference frame realization has gradually decreased to about 45 stations. To improve the stability of the realization, it became apparent that a new realization was necessary (Ray, 2003). Reference Frame Working Group (RFWG) members, namely J. Ray, G. Gendt, M. Heflin, Z. Altamimi and several others, provided many of the suggestions used in the review of "IGS00". One of the main objectives was to stabilize the reference frame realization by increasing the number of stations, ideally up to about 150, thus achieving a network spacing of less than 2000km.

About 200 stations were originally considered, 99 did pass all the selection criterions, the main ones being:

- monumentation,
- geology,
- usage by the ACs,
- performance,
- location with respect to global distribution,
- collocation with other techniques,
- position time series stability,
- agreement with plate model.

To improve the global distribution, the geographical location of potential candidate stations was an important criteria and probably the most difficult one to meet. To achieve a reasonable distribution, some "flexibility" was required at remote sites. The above criterions generally followed the already agreed list from Kouba et al. (1998). As was the case in the past, few stations met equally well all the criterions. There is some subjectivity in the weighting of the criterions used in the selection. For some stations that did experience position time series discontinuities; different solution estimates were used for the alignment and for the realization. In those cases, the velocity estimates for the segments were forced to be unique. The idea was also extended to split the stations between the ones contributing to the alignment to ITRF2000 and those forming the realization. Although most stations are common to both, this approach retained some remote stations that would otherwise have been rejected in the IGb00 realization. Some stations had limited data available when ITRF2000 was made available in 2001. At the time, IGb00 realization was aligned to ITRF2000, the most recent data used in ITRF2000 to estimate the stations position/velocity was at least 3 years old. IGb00 includes data until 2003-08-16 (GPS week 1321). The proposed set for the IGb00 realization did include 99 stations (See Appendix 1).

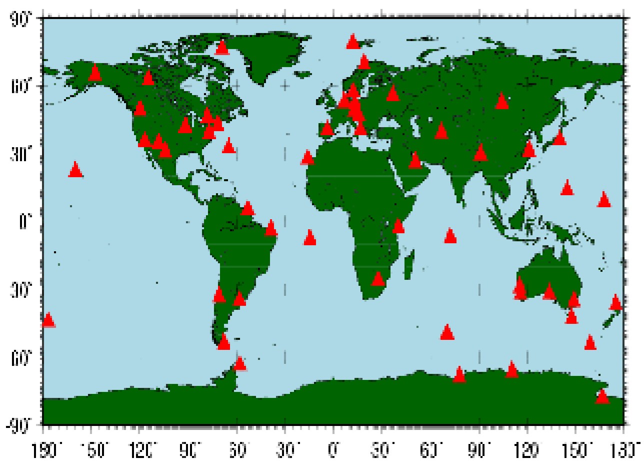
A total of 8 stations from "IGS00" were not retained in the proposed IGb00, they are: BRMU, KWJ1, OHIG, SHAO, THU1, TROM, WSRT and ZWEN.

At 3 sites, alternative stations were used:

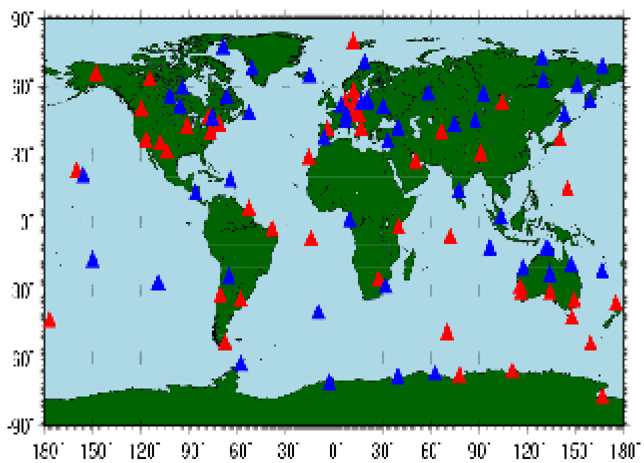
OHIG $\rightarrow$ OHI2,
THU1 $\rightarrow$ THU3,
TROM $\rightarrow$ TRO1.

There are 47 common stations between "IGS00" and "IGb00" (see Appendix 2) and 52 new stations in the proposed "IGb00" (see Appendix 3).

Six sites used in the reference frame realization had experienced significant discontinuities since the original IGS realization and since ITRF2000 became official. For the alignment/realization, independent velocity estimates at a station were combined to provide a unique velocity per site. The six sites with estimated discontinuity are: BILI, COCO, FAIR, GUAM, HOFN and KOKB.



Distribution of the "IGS00" (54 stations) realization of ITRF2000
Figure 7



Distribution of the "IGb00" (99 stations) realization of ITRF2000.
Figure 8

The alignment of "IGb00" to ITRF2000 was done using 71 stations (see Appendix 4). The other stations were not used in the alignment either because: 1) There was significant difference in position and/or velocity between ITRF and its IGS proposed realization or 2) the station was not available in ITRF2000 (see Appendix 5). The RMS of the residuals of the station positions used in the alignment was sub-mm in the horizontal components of position and velocity, and 2.6mm & 1.5mm/y in the vertical.

Due to data and network selection effects, there are some small transformations between "IGS00" and "IGb00" (Table 2). For most applications, this discontinuity is negligible. The RMS of the residuals between the "IGS00" and "IGb00" are (0.3, 0.3, 0.5) mm in position at the reference epoch 1998-01-01 and (0.4, 0.5, 0.8) mm/y in velocity for the north, east and height components. These statistics are also an indication of the effect of adding about two years of weekly solutions to the cumulative solution IGS01P37.snx (IGS00). During the process, the ACs did provide very important feedback, and also had time to experiment with the new realization.

At epoch 1998-01-01	Translations (mm)			Rotations (mas)			Scale (ppb)
	TX	TY	TZ	RX	RY	RZ	S
(-)	-0.1	0.2	0.2	0.001	0.004	-0.006	0.116
Rate (-/y)	0.0	-0.2	-0.1	-0.004	-0.005	0.000	-0.057

Transformation Parameters from "IGb00" to "IGS00" at 1998-01-01
Table 2

The 14-parameter transformation between "IGS00" and "IGb00" was estimated using the 44 common stations (see Appendix 6). The effect of the new IGS realization of ITRF2000 on the ERPs can be predicted with the above estimate of the transformation parameters using formula:

(R X) = (R X)o + (d R X)*dt (1a)

(R Y) = (R Y)o + (d R Y)*dt (1b)

With the procedure used, there are some small approximations because the alignment and realization includes a somewhat different set of stations.

The magnitude of the approximation was verified by using both realizations on eleven GPS weeks (1220-1230) The estimated daily ERP differences ("IGS00"-"IGb00") were computed:

dXp = -0.033 ± 0.005 mas dYp = -0.017 ± 0.007 mas

Using the formula (1), the estimated rotations at GPS week 1225.5 are:

(R X) = -0.024 mas (R Y) = -0.023 mas

Then the residuals between the predicted and the observed effect are:

(R X) - dYp = -0.007 mas (R Y) - dXp = 0.010 mas

The two estimates agree within 0.01mas (~0.3mm on the surface of the Earth). This validates that the "IGS00" and "Igb00" are aligned with an accuracy of about 0.01mas. This also indicates that network effects, other than those predicted by the usual 14 transformation parameters, are very small on the ERP's.

Similarly, the effect of the proposed IGS realization of ITRF2000 on the apparent geocenter can be estimated with the above transformation parameters using formula:

(Xgc) = (T X)o + (d T X)*dt (2a)

(Ygc) = (T Y)o + (d T Y)*dt (2b)

(Zgc) = (T Z)o + (d T Z)*dt (2c)

The same reprocessed weeks were used here to verify the effect of the proposed realization on the apparent geocenter. The difference of the two realizations ("IGS00"–"IGb00") on the apparent geocenter is:

dXGC = -0.4 ± 0.5 mmdYGC = -1.2 ± 0.5 mmdZGC = 0.0 ± 0.6 mm

Using formula (2a-b-c), the estimated effect on the apparent geocenter for GPS week 1225.5 is:

(T X) = -0.3 mm (T Y) = -1.1 mm (T Z) = -0.5 mm

Their differences are:

(T X) - dXGC = 0.1 mm (T Y) - dYGC = -0.1 mm (T Z) - dZGC = 0.5 mm

The two estimates are almost identical (at 0.1mm) in the X&Y components. Although, the difference is larger in the Z component, it is still within the noise level.

A second solution realizing “IGb00” was also prepared (“IGS03P33_RS106.snx”). It includes 7 old reference frame stations (BRMU, KWJ1, OHIG, SHAO, THU1, TROM, ZWEN) that were not retained for the “IGb00” realization. It may be useful for that want to align their products before GPS week 1231.

The “IGb00” was reviewed a few times during years 2003-2004. Information provided by the weekly IGS SINEX combination was used to detect stations of potential concern. Stations with average residuals exceeding ~7/15 mm in the horizontal/vertical components as well as those with normalized average residuals exceeding 5 mm were checked in detail. Stations that were missing at least 50% of the time were also checked. Some have significant seasonal variations and were at the "peak" of their seasonal fluctuations, thus were not rejected. On 2004-04-11 (GPS week 1266), 4 stations were removed from the IGb00 realization (ref: IGSMAIL-4928):

- FAIR – Inaccurate position/velocity estimate in IGb00 due to the Delaini earthquake post-seismic deformation.
- MAG0 – Discontinuity (2003-11-02).
- SFER – Small discontinuity (2003-06-08)
- YSSK - Discontinuity due to Hokkaido earthquake (2003-09-25).

Station KOKB was removed starting on 2004-06-06 (GPS week 1274) due to a station position discontinuity likely caused by an antenna change (ref: IGSSTATION-47). Station TRO1 was also removed starting on 2004-08-08 (GPS week 1283) due also to a discontinuity likely caused by an antenna change (ref: IGSSTATION-123).

Apriori Constraints in AC solutions

The first recommendation from the "Reference Frame Maintenance" session (Ferland et al. 2004) from the Bern workshop suggested reviewing the constraints and their effect on the AC solutions. The objective of the recommendation was to assess the effect of direct & indirect apriori constraints on the AC weekly SINEX solutions. This should also provide a measure of the coupling between the parameters reported in the SINEX files and the other parameters. Most AC SINEX solutions are currently either loosely constrained or unconstrained. However, parameters in some AC solution still show evidence of unreported constraints in the weekly solutions. Between 2004-04-25 and 2004-05-15 (GPS weeks 1268-1270), the AC were asked to provide unconstrained solutions on all parameters along with their “production” weekly solutions. In the cases where “truly” unconstrained solutions were impossible, loosely constrained solutions could be submitted. All other variables in the provided solutions were to be identical (e.g.: network and model).

In the analysis, the effect of the constraints on the “production” solutions was verified by removing the constraints. Table 3 shows the RMS on the stations position solutions after aligning the “production” constrained and unconstrained solutions. In all cases the effect of the constraints is sub-mm. COD, ESA and NGS (for a shorter period) had non-removable continuity conditions on the pole rates. The inclusion of those pole rates in the combined solution would cause the condition to be automatically present in the IGS combined product. To avoid this, the pole rates for those AC’s were not included in the combined products. GFZ had some non-removable constraints on the apparent geocenter, it was excluded from the solution. JPL already provided unconstrained weekly solutions and EMR only used inner constraints.

	1268			1269			1270		
	N	E	H	N	E	H	N	E	H
COD	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.0	0.0
EMR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ESA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GFZ	0.3	0.2	0.7	0.3	0.3	0.8	0.3	0.4	0.9
JPL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MIT	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.4
NGS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SIO	0.4	0.2	0.6	0.3	0.2	0.5	0.1	0.1	0.6

Station coordinates residuals RMS (mm) of the constrained and unconstrained "production" solution
Table 3

Table 4 shows the RMS of the position differences between the production solutions (after un-constraining) and the provided unconstrained solutions. The solutions were aligned to each other before differencing. The results from the EMR and GFZ solutions indicates that the constraining effects are sub mm horizontally, and mm level vertically, and negligible for JPL and MIT. The data from other ACs was unavailable.

	1268			1269			1270		
	N	E	H	N	E	H	N	E	H
COD	-	-	-	-	-	-	-	-	-
EMR	0.2	0.5	0.8	0.4	0.3	0.9	0.3	0.4	1.0
ESA	-	-	-	-	-	-	-	-	-
GFZ	0.7	0.3	1.1	0.6	0.4	0.9	0.7	0.5	1.0
JPL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MIT	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.4
NGS	-	-	-	-	-	-	-	-	-
SIO	-	-	-	-	-	-	-	-	-

Station coordinates residuals RMS (mm) of the unconstrained "production" and "test" solutions
Table 4

Occasionally, there are numerical problems inverting the apriori and/or estimated matrices because they become singular. In those cases, small (~ppb) rescaling is applied to the matrices and/or their diagonal is sufficient.

Position Time Series Discontinuities

With GPS, stations position discontinuities do occur from time to time. They have 2 main causes: geophysical and equipment changes. When doing station position time series analysis, the discontinuities can potentially have an important impact on the results. The requirement for an inventory of such discontinuities has been recognized for some time (Ferland et al. 2004). An inventory including two discontinuity tables has been prepared. The first table contains a list of confirmed discontinuities; the second table contains a list of probable discontinuities. A "confirmed" discontinuity occurs when it was present in all/most time series that were checked, and could be correlated with an event (e.g.: geophysical or equipment change). The discontinuity table format is an extension of SINEX and is described in the above reference. All the stations that were provided by the ACs 1) since 1996-01-21 (GPS week 0837) and 2) with station log at the IGSCB were checked. For the coordinates and residual time series time, the following sources were used:

IGS (ftp://macs.geod.nrcan.gc.ca/pub/requests/sinex/coord_r)
JPL (http://sideshow.jpl.nasa.gov/mbh/series.html)
MIT (http://www-gpsg.mit.edu/~tah/MIT_IGS_AAC/index2.html)
SIO (http://sopac.ucsd.edu/cgi-bin/refinedTimeSeriesListing.cgi)

The IGS time series goes back to 1996-01-21 (GPS week 837). For events before that time, JPL and SIO were the main source of information.

The station logs available at the IGS central bureau (http://igscb.jpl.nasa.gov/network/list.html) were used to attempt to correlate discontinuities with equipment changes. When discontinuities were likely caused by equipment change, the time tag reported in the tables refer to the equipment change. Information from the (USGS) Earthquake Hazards Program (http://earthquake.usgs.gov/activity/past.html) was also used to correlate discontinuities with surrounding earthquake activity. When such correlation was possible, the earthquake time tag was used. Regional centers (EUREF & NAREF) also provided important feedback to ensure consistency between the global and regional solutions.

Solution # are currently in chronological order. As new discontinuities are discovered, and as new stations are added, the lists are updated.

For discontinuities of unknown source, the time of the discontinuity is the beginning/end of the nearest week. For small events, the identification of a discontinuity is often somewhat subjective. This subjectivity was apparent, as small discontinuities were sometimes flagged in some time series and not in others (or sometimes not even visible). In case of doubt, the discontinuities were put in the probable list. In the cases of station position temporary excursions, the events were not flagged. Up to date tables can be found in:
(ftp://macs.geod.nrcan.gc.ca//pub/requests/sinex/discontinuities)

Time Series Tables

Time series and corresponding diagrams prepared from the IGS SINEX weekly products (and updated weekly) are available at:
(ftp://macs.geod.nrcan.gc.ca//pub/requests/sinex)
For details about the format and file naming convention, see the files:

README_coord
README_erp
README_res
README_sum.

Sub-directories containing the tables extracted from the official IGS products and corresponding graphical files:

- coord - coordinates time series
- erp - ERP residuals time series
- res - Station coordinates residuals time series
- sum - Summary time series

Tables and corresponding graphics are also available for reprocessed IGS products. The directories are: coord_r, erp_r, res_r and sum_r. They are updated as needed.

SUMMARY

The IGS cumulative solution now contains about 484 stations among which 278 are made available weekly. The weekly solution currently includes about 250 stations. The IGS realization of ITRF uses a subset of the IGS cumulative solution. The “IGS00” which originally used 54 stations was augmented and replaced by a new realization “IGb00” which included 99 stations. When “IGS00” was replaced there were 45 active stations remaining. The consistency of station positions, ERPs and apparent geocenter show sings of gradual improvement. The impact of different strategies used by ACs to apply constraints when estimating their solution was reviewed. The AC solutions tested indicated that there is no significant effect on the station positions. In some cases, the ERPs and apparent geocenter are affected by unremovable constraints. In those cases, the parameters of concern are removed form the AC solutions before the weekly products are combined. Station position time series discontinuities do occur from time to time. An inventory of the stations position time series discontinuities was also prepared. Time series of the official IGS SINEX products and of reprocessed products are available via ftp.

ACKNOWLEDGEMENTS

A large number of agencies contribute to IGS. Among them are the agencies responsible for the installation and maintenance of the tracking stations, the regional and global data centers in addition to the ACs and GNAACs already mentioned. A complete list of contributors can be found at the IGS web site (http://igscb.jpl.nasa.gov/). Also thanks to Pierre Héroux and Martin Bourassa for reviewing this report.

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APPENDICES

Appendix 1:

The proposed 99 stations in IGb00:
ALGO ALIC ARTU ASC1 AUCK BAHR BILI BOR1 BRUS CAS1 CEDU CHAT CHUR COCO CRO1 DARW DAV1 DGAR DRAO DUBO EISL FAIR FLIN FORT GLSV GODE GOLD GOUG GRAS GRAZ GUAM HOB2 HOFN HRAO IISC IRKT JAB1 JOZE KARR KELY KERG KIT3 KOKB KOUR KSTU LAMA LHAS LPGS MAC1 MAG0 MALI MANA MAS1 MATE MAW1 MCM4 MDO1 MKEA NICO NKLG NLIB NOUM NRC1 NTUS NYAL OHI2 ONSA PERT PETP PIE1 POL2 POTS RBAY RIOG SANT SCH2 SFER STJO SYOG THTI THU3 TIDB TIXI TOW2 TRAB TRO1 TSKB UNSA URUM VESL VILL WES2 WSRT WTZR YAKT YAR1 YELL YSSK ZIMM.

Appendix 2:
Common stations (47) between “IGS00” and “IGb00”:
ALGO ASC1 AUCK BAHR CAS1 CEDU CHAT DAV1 DGAR DRAO FAIR FORT GODE GOLD GRAZ GUAM HOB2 HRAO IRKT KERG KIT3 KOKB KOUR LHAS LPGS MAC1 MALI MAS1 MATE MCM4 MDO1 NLIB NYAL ONSA PERT PIE1 POTS RIOG SANT TIDB TSKB VILL WES2 WSRT WTZR YAR1 YELL,

Appendix 3:
New stations (52) in the proposed in “IGb00”:
ALIC ARTU BILI BOR1 BRUS CHUR COCO CRO1 DARW DUBO EISL FLIN GLSV GOUG GRAS HOFN IISC JAB1 JOZE KARR KELY KSTU LAMA MAG0 MANA MAW1 MKEA NICO NKLG NOUM NRC1 NTUS OHI2 PETP POL2 RBAY SCH2 SFER STJO SYOG THTI THU3 TIXI TOW2 TRAB TRO1 UNSA URUM VESL YAKT YSSK ZIMM.

Appendix 4:
Common stations (71) between “IGb00” to ITRF2000:
ALGO ASC1 AUCK BAHR BOR1 BRUS CAS1 CHAT CHUR COCO DAV1 DGAR DRAO DUBO EISL FAIR FLIN FORT GLSV GODE GOLD GRAS GRAZ HOB2 HOFN HRAO IISC IRKT KARR KELY KERG KIT3 KOUR KSTU LAMA LHAS LPGS MAC1 MAS1 MATE MAW1 MCM4 MDO1 MKEA NLIB NOUM NRC1 NTUS NYAL ONSA PERT PIE1 POL2 POTS RIOG SANT SCH2 STJO SYOG TIDB TIXI TOW2 TROM TSKB VILL WES2 WSRT WTZR YAR1 YELL ZIMM

Appendix 5:
Stations (28) available in “IGb00” and not in ITRF2000:
ALIC ARTU BILI CEDU CRO1 DARW GOUG GUAM JAB1 JOZE KOKB MAG0 MALI MANA NICO NKLG OHI2 PETP RBAY SFER THTI THU3 TRAB TRO1 UNSA URUM VESL YAKT YSSK

Appendix 6:

Common stations (44) between “IGS00” and “IGb00” used to estimate the transformation parameters:

ALGO ASC1 AUCK BAHR CAS1 CHAT DAV1 DGAR DRAO FAIR FORT GODE GOLD GRAZ HOB2 HRAO IRKT KERG KIT3 KOUR LHAS LPGS MAC1 MALI MAS1 MATE MCM4 MDO1 NLIB NYAL ONSA PERT PIE1 POTS RIOG SANT TIDB TROM TSKB VILL WES2 WTZR YAR1 YELL

ITRF and IGS Reference Frame Relationship

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Abstract
The relationship between the International GNSS Service (IGS) and the International Earth Rotation and Reference Systems (IERS) is particularly enforced through the activities related to International Reference Frame (ITRF). This report summarizes the activities of the IERS/ITRF Product Center of concern to the IGS, during the period 2003 – 2004. Results of some specific analysis of the IGS combined time series of station positions and Earth Orientation Parameters are included in this report. In particular some analysis tests were performed in order to evaluate the stability of the IGS reference frame over the origin, scale and orientation.

1. Introduction
Since its inception, the IGS contributes to and improve the realization of the International Terrestrial Reference Frame. The IGS is maintaining more than 350 permanent stations thanks to the participation of national agencies worldwide. The density and quality of the IGS network make the ITRF easily and accurately accessible anywhere using precise IGS products. It also facilitates the implementation of the rotational time evolution of the ITRF in order to satisfy the No Net Rotation condition over tectonic motions of the Earth's crust. Accurately linking polar motion to the reference frame is one additional important contribution of the IGS observing permanent network.

IGS uses its own ITRF realization, based on GPS only, but fully consistent with the ITRF. The reason is that there are still some unresolved discrepancies between IGS/GPS and other techniques in collocated sites, most probably due to, e.g. dubious local ties and/or technique-specific (including GPS antenna) effects. Using ITRF station positions and velocities directly to generate IGS products would introduce distortions and inconsistencies that could not otherwise be easily isolated or controlled. Among other problems, this would hinder progress in understanding and reducing existing internal GPS error sources. This does not imply that the GPS frame is necessarily superior to ITRF or those of other techniques, only that it is more self-consistent. Any common mode errors in the IGS frame that are suppressed by the use of GPS-only results (such as possible scale defects) must be investigated separately, for example in multi-technique combinations. To maintain full internal self-consistency, since 2000 the IGS forms a secondary GPS-only frame of reference coordinates and linear velocities from the same contributed solutions used for its other products. The "IGS00" frame (currently the second version, IGb00) is aligned to ITRF2000, over the 14 transformation parameters, using a selected subset of high-quality stations (recently increased from 54 to 99). This procedure fully preserves the reference datum of ITRF2000 (including scale), but without any internal distortions. IGS00 is then used as the direct basis for all other IGS products. For more discussion on consistency of IGS products and other IGS reference frame issues, see Ray et al (2004).

Aiming at evaluating the stability of the IGS frame over time, some time series analysis were performed using the current version of the IGS ITRF2000 realization, namely the IGb00. CATREF software developed at IGN for the ITRF combinations was used to assess the impact of changing the configuration of the reference set of stations. In order to define the combined frame under minimum constraints condition, we used different sets of stations, but still globally distributed, extracted from the IGb00 reference set. Using this approach, we try to assess the behavior and stability over time of the origin, scale and orientation as well as Earth Orientation Parameters, by comparing the different realizations while varying the number and distribution of reference stations. All the detailed results of these analysis were presented at the IGS Workshop held in Berne in 2004, (Altamimi and Ray, 2004).

2. CATREF Combination model

The initial model implemented in CATREF software allows simultaneous combination of station positions and velocities. A large description could be found in (Altamimi et al. 2002). Assuming that for each individual solution ***s***, and each point ***i*** , we have position $\mathbf{X}^{i}_{s}$ at epoch $\mathbf{t}^{i}_{s}$ and velocity $\dot{X}^{i}_{c}$, expressed in a given TRF **k**.

The combination consists in estimating:

- Positions X^{i}_{c} at a given epoch $\mathbf{t_0}$ and velocities $\dot{X}^{i}_{c}$, expressed in the combined TRF ***c***,
- Transformation parameters $\mathbf{T_k}$ at an epoch $\mathbf{t_k}$ and their rates $\mathbf{T_k}$, from the combined TRF ***c*** to each individual frame **k**.

The general combination model is given by the following equation:

$$\begin{cases} X^{i}_{s} = X^{i}_{c} + (t^{i}_{s} - t_0) + T_k + D_k X^{i}_{c} + R_k X^{i}_{c} \\ \quad + (t^{i}_{s} - t_k)[\dot{T}_k + \dot{D}_k X^{i}_{c} + \dot{R}_k X^{i}_{c}] \\ \dot{X}^{i}_{s} = \dot{X}^{i}_{c} + \dot{T}_k + \dot{D}_k X^{i}_{c} + \dot{R}_k X^{i}_{c} \end{cases}$$

Using pole coordinates $\mathbf{x^p}_s$, $\mathbf{y^p}_s$ and universal time UT_s as well as their daily time derivatives $\dot{x}^{p}_{s}, \dot{y}^{p}_{s}$ and LOD_s, the corresponding equations are :

$$\begin{cases} x^p_s = x^p + R2_k \\ y^p_s = y^p + R1_k \\ UT_s = UT - \frac{1}{f} R3_k \\ \dot{x}^p_s = \dot{x}^p + \dot{R}2_k \\ \dot{y}^p_s = \dot{y}^p + \dot{R}1_k \\ LOD_s = LOD + \frac{\Lambda}{f} \dot{R}3_k \end{cases}$$

where f = 1.002737909350795 is the conversion factor of UT into sideral time. Considering LOD = $\Lambda_0 \frac{dUT}{dt}$, Λ_0 is homogenous to time difference, so that Λ_0 = 1 day in time unit.

Note that the link between EOP and TRF is ensured upon the 3 rotation angles R1, R2, R3, and their time derivatives.

In order to precisely define the datum of the combined frame minimum constraints equations were implemented in CATREF software, allowing to express the combined solution in any external frame. For more details concerning equations of minimum constraints and their practical use, see for instance Altamimi et al., (2004).

CATREF Software is well adapted for time series combination by a rigorous stacking and using different ways to define the combined frame in terms of origin, scale and orientation. The most favored datum definition approach currently adopted in CATREF combination analysis is the use of Minimum Constraints (Altamimi et al., 2004). When stacking the daily/weekly solutions using equations of the combination model described above, the constructed normal equation system is singular and has 14 degrees of freedom. This rank deficiency corresponds to the number of parameters which are necessary for the datum definition of the combined Terrestrial Reference Frame (TRF). The latter is defined through minimum constraint approach using the equation:

$$(A^T A)^{-1} A^T (X_c - X_R) = 0$$

where $\boldsymbol{X_c}$ and $\boldsymbol{X_R}$ are the combined and reference solutions, respectively. $\boldsymbol{A}$ is the design matrix of partial derivatives of the 14 TRF parameters

3. Evaluation of the IGS Reference Frame Stability

3.1 Analysis Strategy

Since the IGS weekly combined solutions are generated under minimum constraints condition (Ferland, 2003), they were used directly as they are in the CATREF analysis. The main outputs of this analysis are time series of the three origin components, the scale parameter and the Earth Orientation Parameters and in particular polar motion component x-pole and y-pole.

3.2 Data Analysis

To study the time behavior of the frame parameters and polar motion as described above, we first performed two combinations of the IGS SINEX files where the combined frame is defined by the 54 stations in the first combination and by the current 99 stations in the second combination (Figure 1). As result from these two combination, Figure 2 illustrates the differences in time variation of the origin components as well as the scale, and Figure 3 shows the differences in polar motion. One should notice that the resulting differences are mainly a shift and a drift over time. Regarding the polar motion differences (Figure 3), they are still within the uncertainties of the considered period, but exceed the uncertainty level beyond that period.

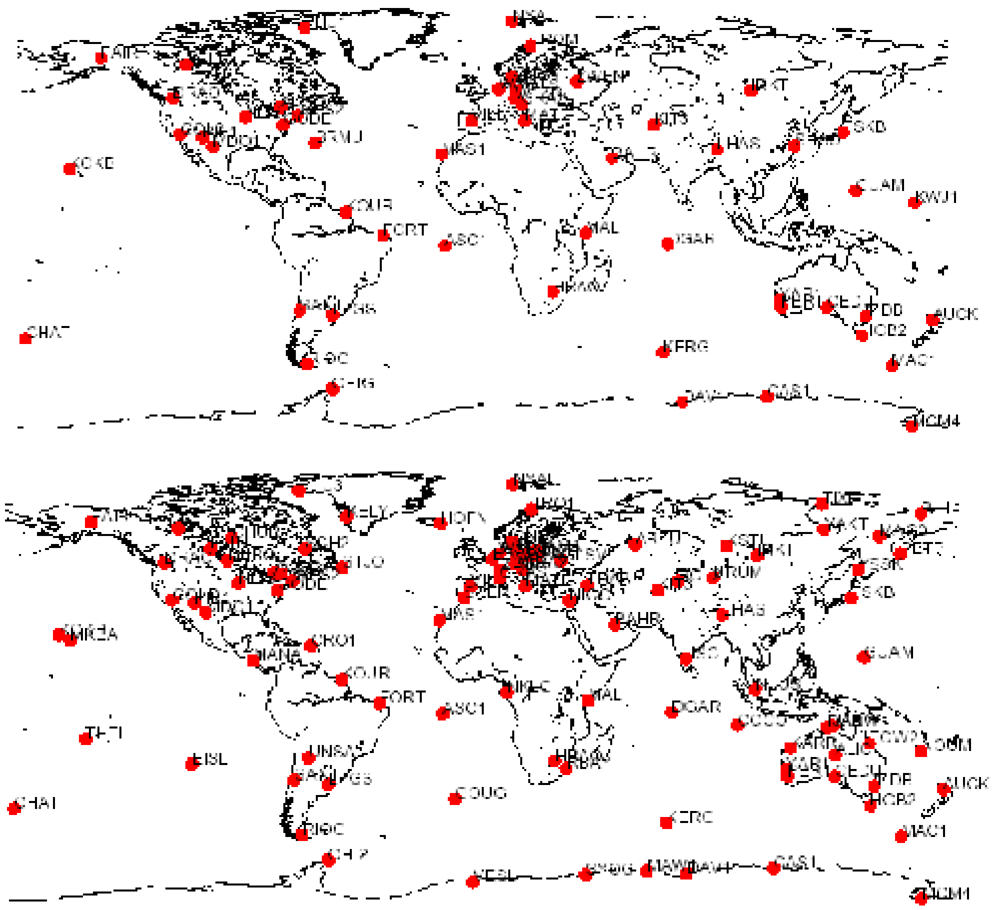

Figure 1. IGS00 Network: 54 stations (Top) and 99 stations (Bottom)

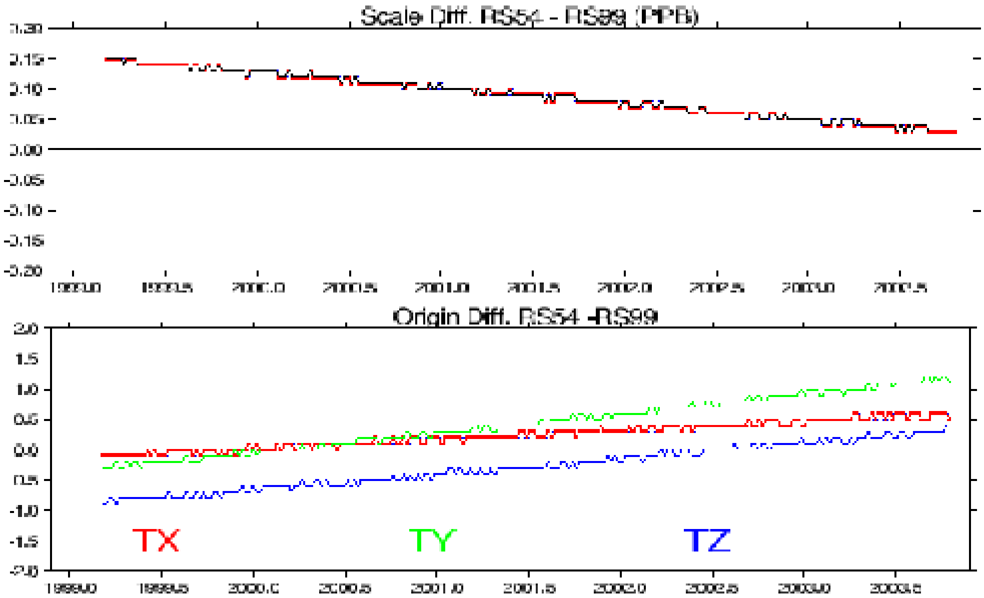

Figure 2. Scale and origin differences in time when changing the reference set from 54 to 99 stations

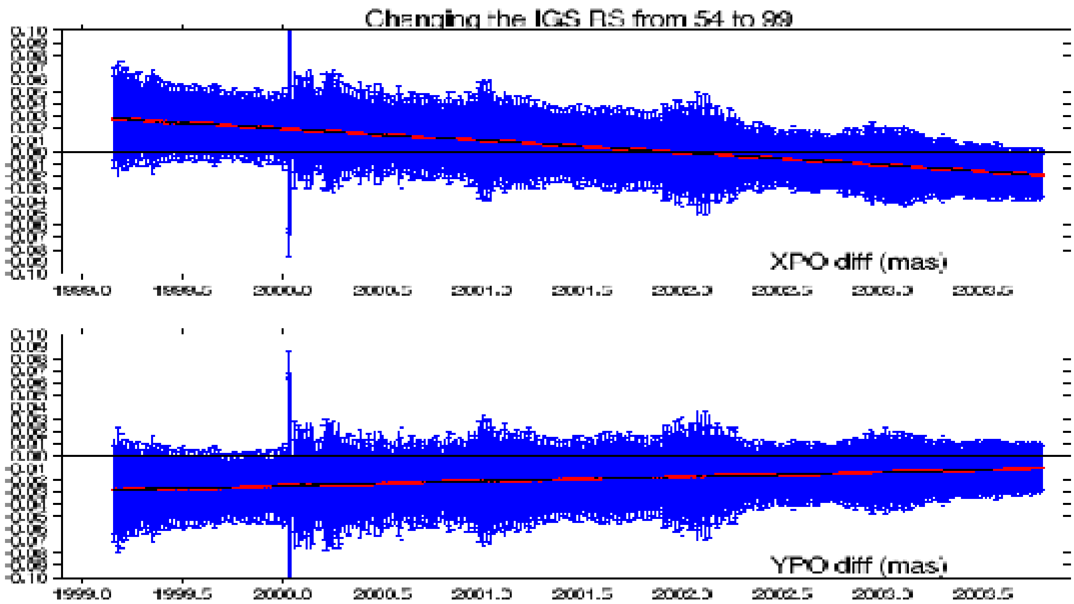

Figure 3. Polar motion differences in time when changing the reference set from 54 to 99 stations.

We then performed 10 combinations using different reference sets comprising 25 and 50 stations, but still globally distributed to evaluate the network effect on the frame stability over time. As an example, Figure 4 shows the scale and origin differences between a combination using 50 stations as reference set, compared to the combination with 99 stations, and Figure 5 shows the differences in polar motion.

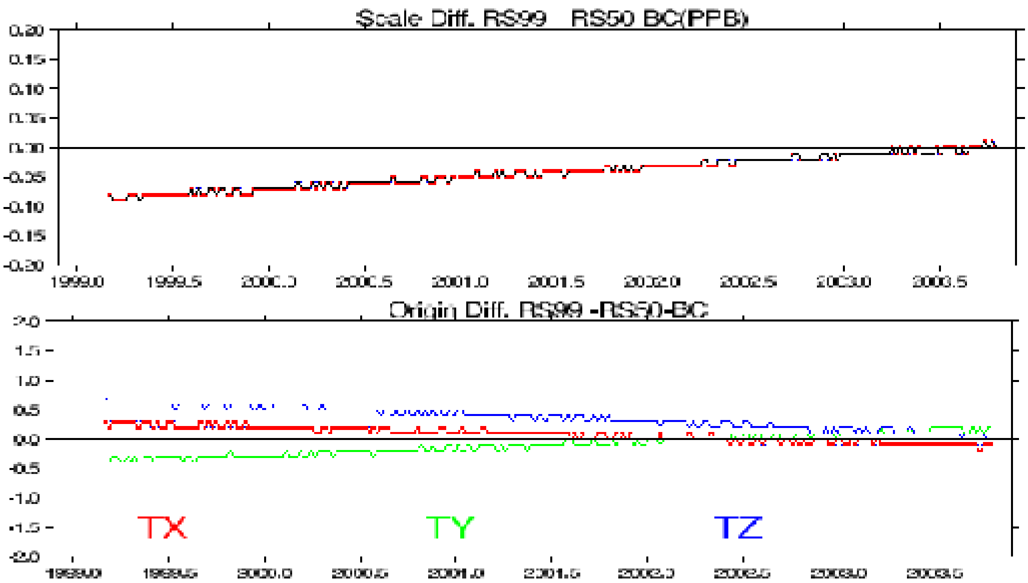

Figure 4. Scale and origin differences in time when using 50 stations as reference compared to a combination using 99 stations

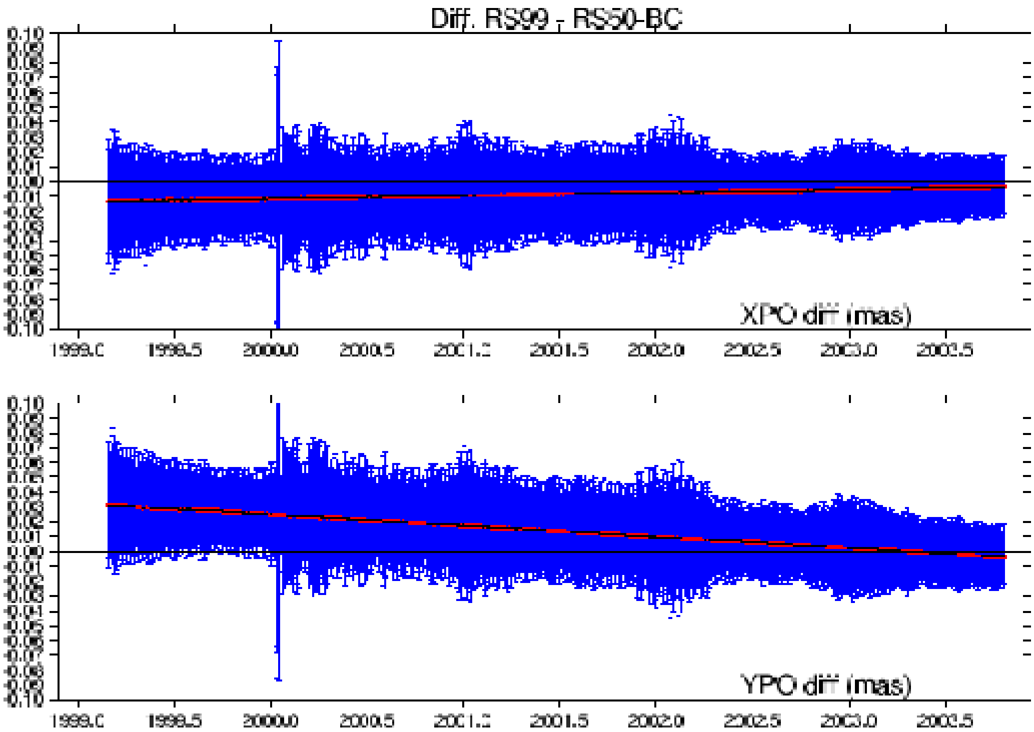

Figure 5. Polar motion differences in time when using 50 stations as reference compared to a combination using 99 stations.

Moreover, in order to evaluate the impact of discontinuities in the time series, we performed a combination in which we imposed equal station velocities for Arequipa site before and after the earthquake occurred on day 174 of year 2001. Figure 6 shows the impact on polar motion, exactly at the earthquake day and after; a rupture of 40 micro-arc-seconds is visible.

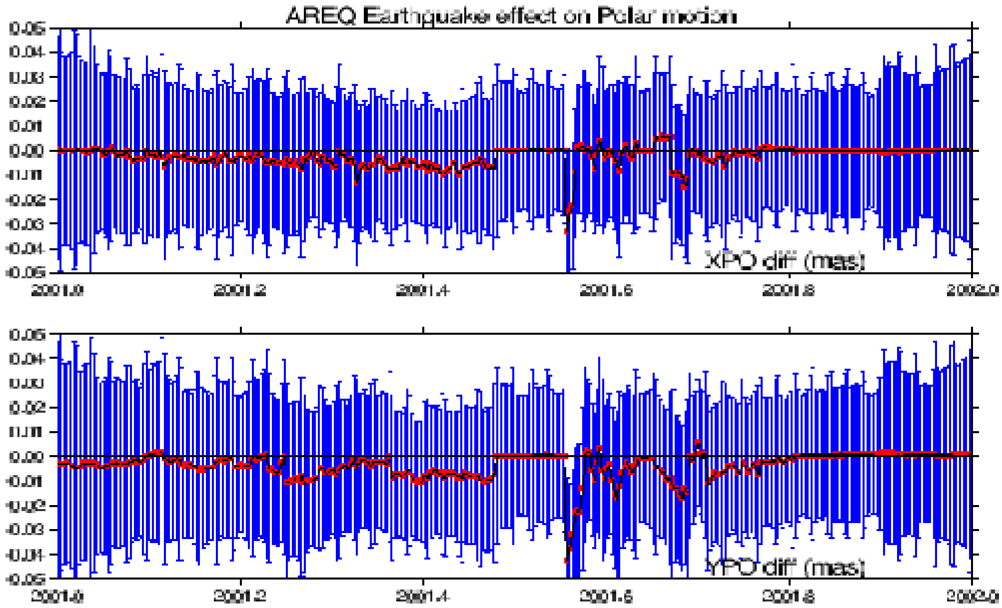

Figure 6. Impact of AREQ Earthquake on Polar Motion if pre & post station velocity is constrained to be the same

Finally, the procedure adopted for time series combination allow us to evaluate the quality of the TRF in terms of repeatability, that is by computing the weekly WRMS over station position residuals. Figure 7 plots the computed WRMS per week as results from the combination using the 99 stations as reference set.

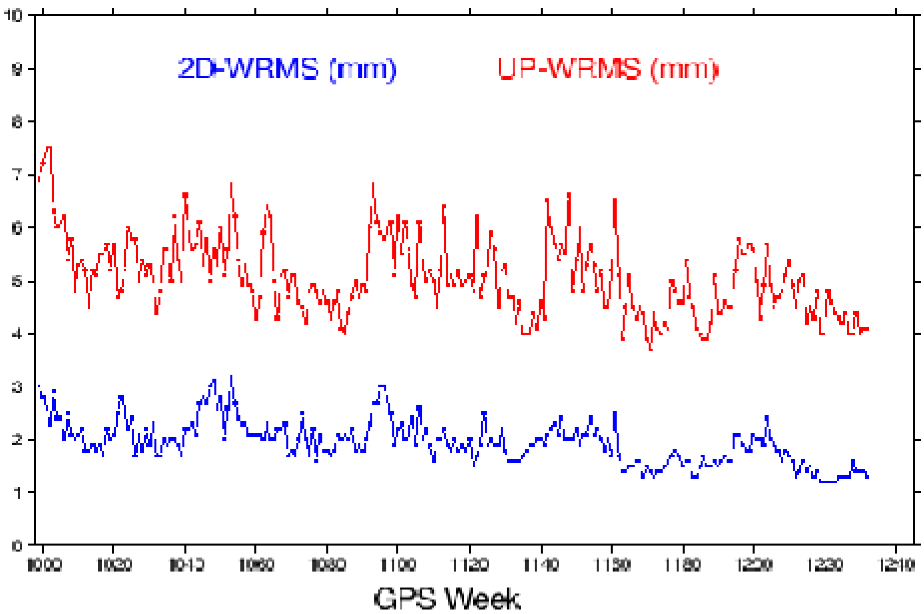

Figure 7 Weekly WRMS computed over station position residuals

4. Conclusion

Ideally, to accurately maintain the stability of the IGS terrestrial reference frame over time, a unique well distributed set of reference stations is desirable. But this is hardly achievable to maintain exactly the same number of the RS, for many operational and technical reasons. Therefore it is advisable to have as many reference stations as possible (but globally distributed) in order to minimize the impact on the TRF when stations are dropped or no longer operational. However, from the analysis presented in this paper, we can conclude that the overall IGS TRF stability is believed to be at the one mm level, noting that the change of reference set may produce changes up to 0.5 mm/yr in origin and scale and about 10 micro-arc-seconds per year in polar motion. The quality of the IGS weekly SINEX files, in terms of WRMS, is around 2 mm horizontally and 5-6 mm vertically. Special care should be observed for discontinuities in the time series because of their impact on frame parameters as well as on polar motion.

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The Newcastle GNAAC Annual Report for 2003-2004

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The GNAAC at University of Newcastle continued activities with submissions of weekly G-network and stopped submitting the P-network SINEX files. The analysis procedure outlined previously (Nurutdinov et al., 2004) remained unchanged throughout the years 2003-2004 (GPS weeks 1200-1303) except of introduction of producing the combined solutions for Earth Rotation Parameters (X_p, Y_p, LOD) starting with week 1159. The IGS00 realization (54 stations) of ITRF2000 has been used to constrain the solutions for GPS weeks 1143-1274. Starting with GPS week 1275 it has been replaced with IGSb00 realization (99 stations) of ITRF2000.

G-network results

A-network SINEX data from all eight global analysis centres (COD, EMR, ESA, GFZ, JPL, MIT, NGS, SIO) were processed. MIT started to submit its solutions from week 1245. The appearance of a station in a minimum of three solutions defines a global station for inclusion in the combined NCL G-network.

The loose G-network solution (GNET) is estimated from block of normal equations composed of each de-constrained A-network. The corresponding covariance matrix is augmented to remove Helmert rotation parameter constraints. This solution is constrained later to the CORE network – either IGS00 or IGSb00 solution on the respective time intervals.

Figure 1 shows the weighted RMS of residuals for each weekly A-network solution after Helmert transformation to the weekly loose G-network solution for the years 2001-2004. The thick solid lines on the Figures 1-9 represent the regression polynomial of the order 10. The table below presents minimum, maximum, mean and standard deviation values for weighted RMS. High values for JPL are the result of the fact that JPL doesn't provide correct reference points for several stations in their solutions. The same happens with some ESA solutions.

	COD	EMR	ESA	GFZ	JPL	MIT	NGS	SIO
Min, mm	0.7	2.8	2.9	0.3	7.0	1.1	1.0	1.8
Max, mm	11.9	20.0	49.2	8.4	155.8	3.4	14.7	7.3
Mean, mm	3.6	3.9	6.3	1.7	48.5	1.8	5.5	3.3
RMS, mm	1.4	1.8	6.1	0.9	37.7	0.5	2.0	1.3

Figure 2 shows scale factors of Helmert transformation from deconstrained AC and GNET solutions to CORE network. Regression reveals periodical-like signal in all solutions.

Figures 3 through 6 show the translational parameters for 7-parameter Helmert transformation from deconstrained AC and loose GNET solutions to CORE network. For GNET, the RMS are 0.32 cm for T_x and T_y and 1.01 cm for T_z on the interval of the years 2003-2004.

Earth Rotation Parameters results

Comparison of constrained GNET, IGS and IERS(C04) solutions for ERP is given on figures 7-9 for the years 2003-2004. The horizontal axes represent the number of days elapsed from 0h January 1, 2003. RMS values between constrained GNET and the IGS, aligned to ITRF2000, ERP solutions are 66 μas (2 mm) for Xp, 44 μas (1.3 mm) for Yp and 10.7 μs (4.5 mm) for LOD.

Other activity

The methodology to invert deformation of the solid Earth for a specific surface mass distribution consistent with static ocean equilibrium theory, and finding, how to transform loading equations between frames, are described in (Blewitt et al, 2004).

An online SINEX-checking facility to assist ACs in submitting SINEX files has been operating at http://ucscgi2.ncl.ac.uk/~nkn3.

Acknowledgements

The activity of NCL GNAAC has been funded by NERC, UK.

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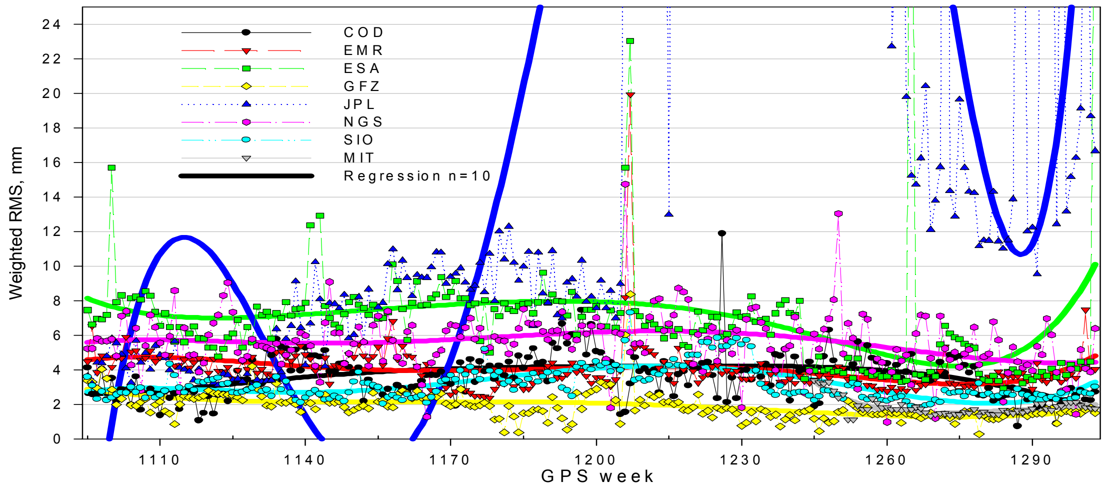

Figure 1. Weighted RMS of residuals for AC network transformation to loose NCL G-network

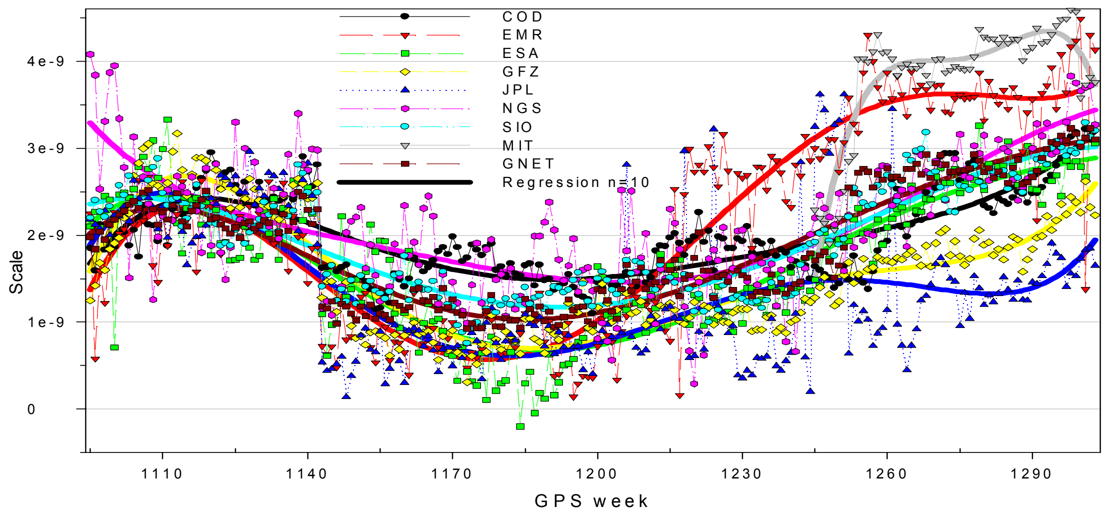

Figure 2. Scale parameter for ACs and NCL GNET to IGS

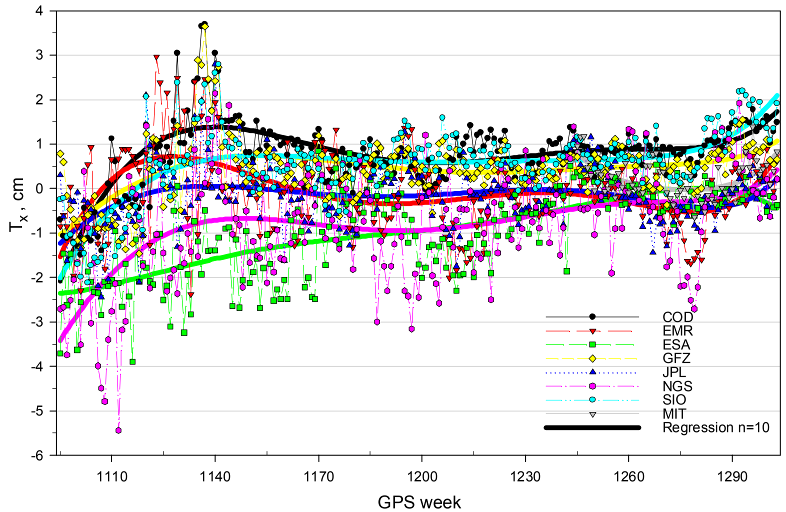

Figure 3. T_x transformation parameter for the ACs to IGS

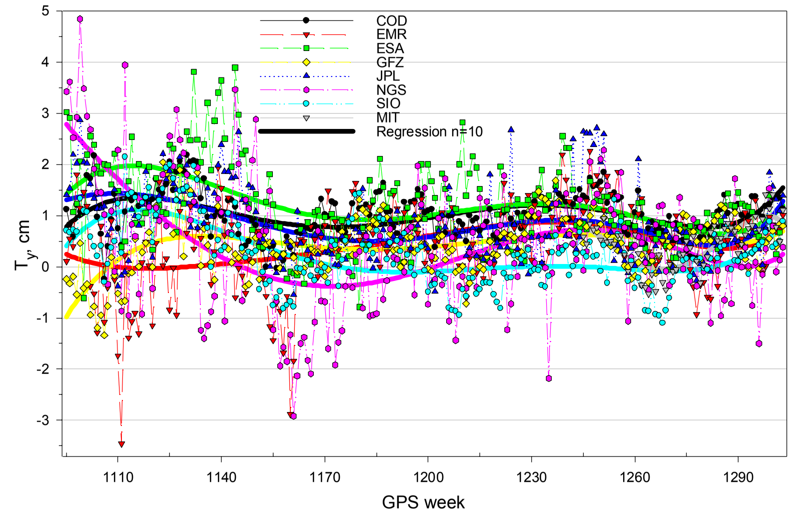

Figure 4. T_y transformation parameter for the ACs to IGS

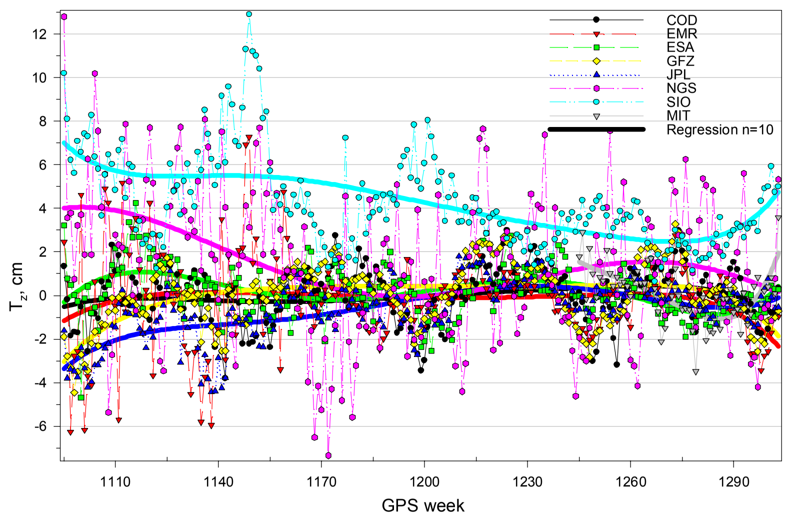

Figure 5. T_z transformation parameter for the ACs to IGS

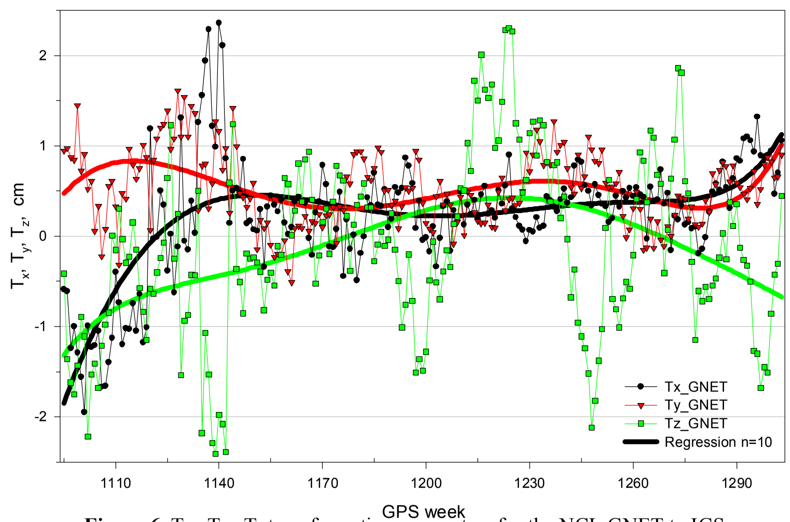

Figure 6. T_x , T_y , T_z transformation parameters for the NCL GNET to IGS

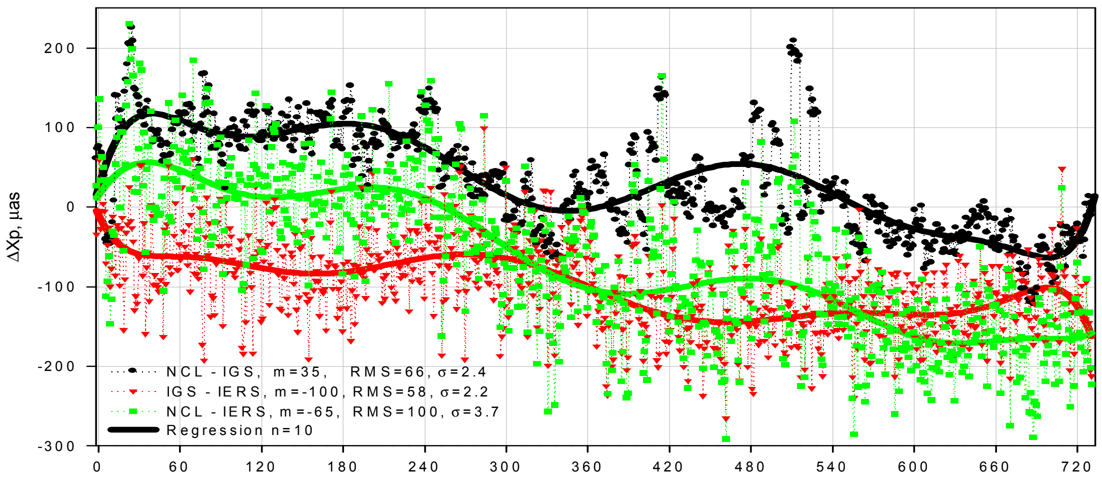

Figure 7. Differencies of Xp coordinate between NCL, IGS and IERS(C04)

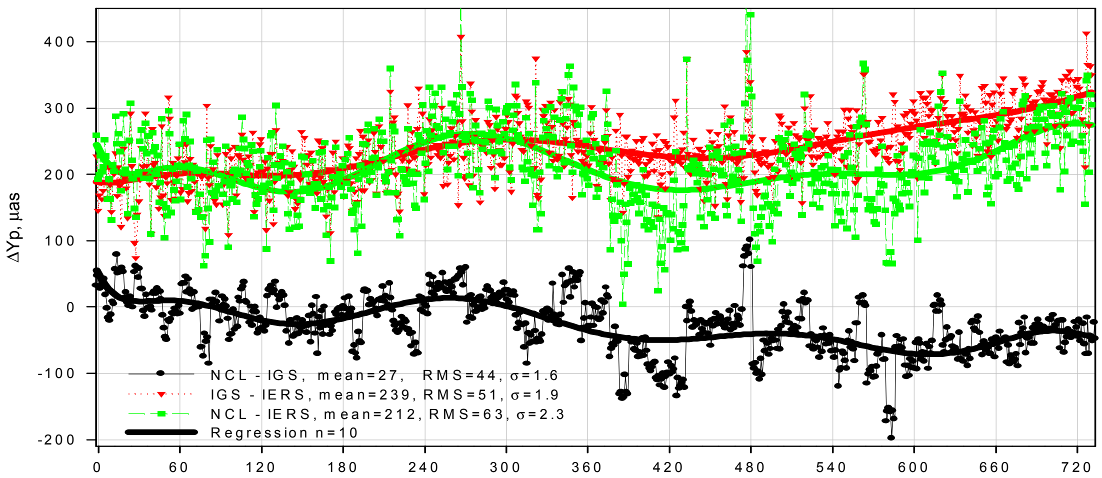

Figure 8. Differencies of Yp coordinate between NCL, IGS and IERS(C04)

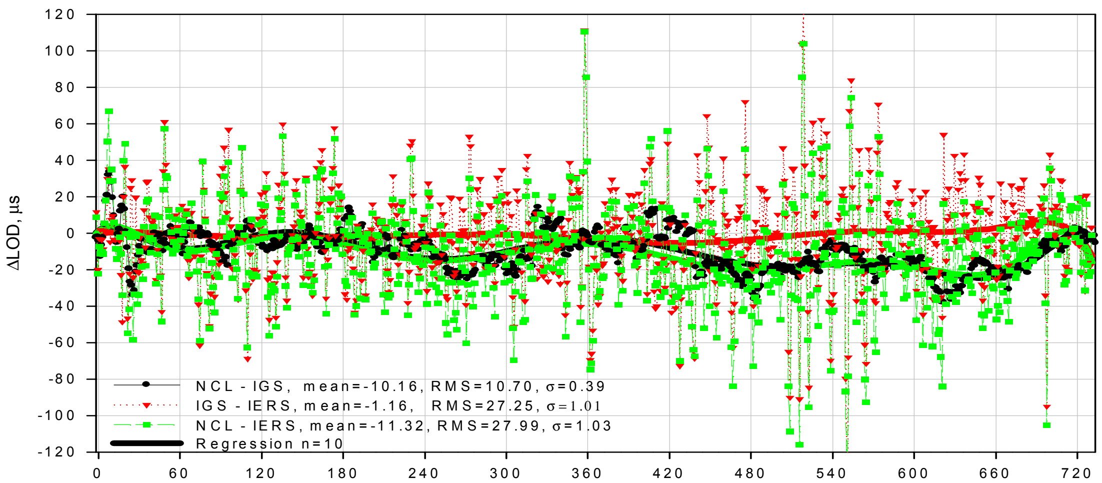

Figure 9. Differencies of LOD between NCL, IGS and IERS(C04)

MIT T2 ASSOCIATE ANALYSIS CENTER REPORT 2003-2004

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Introductiion

We discuss the analysis of the 2003-2004 combined solutions generated from the SINEX files submitted by the IGS analysis centers. We highlight the changes to the analysis procedures reported in previous annual reports. Analysis of our combined solutions shows mean fits to the up to 49, and on average 43, IGS reference sites in the P041 solution of 3.0 mm. For the G-SINEX combinations the median root-mean-square (RMS) repeatability in north, east, and height are 1.5, 1.6 and 5.4 mm, respectively for 256 sites. For the P-SINEX combinations, the median RMS repeatabilities are 1.6, 1.8, and 6,0 mm, respectively for 376 sites. The root mean square (RMS) scatter of the differences between daily pole position and IERS Bulletin A values is 0.08 milli-arc-seconds (mas) for both X- and Y-pole position. However, there are mean differences in Y-pole position of 0.39 mas (2001.0) and a rate of –0.09 mas/yr. The RMS scatters of the differences in polar motion rates are 0.09 mas/day for both components. For length-of-day (LOD), the RMS difference to Bulletin A is 0.023 milliseconds (ms).

Analysis procedure changes

As reported previously [*Herring*, 1996,1997, 2000, 2002], two analyses are performed each week. One of these analyses uses the IGS Analysis Center (AC) weekly A-SINEX files to generate a combined G-SINEX file, and the other uses the Regional Analysis Center (RAC) R-SINEX files combined with the G-SINEX file to generate weekly P-SINEX files. During 2003 and 2004, the G-SINEX files contain 104 sites used every week, 274 sites that were used more than 50 times during the two years and 327 sites that were used at least 8 times. The corresponding values for the P-SINEX files are 116, and 739 sites, and 1030 respectively. The G- and P-SINEX analyses are performed with 2 and 7 weeks delays.

The basic procedures we use are documented in the weekly summary files submitted with the combined SINEX files. During the 2003-2004 interval, we used the IGS realization of ITRF2000 as given in IGb00 as realized in IGS03P33_RS99. Starting in week 1203, we changed the method used to compute the variance scaling factors. In the new method, the RMS difference between the center estimate of the positions of the IGS03P33_RS99 sites are used to scale the variance such the chi-squared-per-degree of freedom after removal of any outliers unity. The approach leads to larger scaling factors, because of non-secular motions of the IGS03P33 sites, but avoided problems with individual centers dominating the combination. We have dropped a number of stations from use in the reference definitions. After 2002/11/03, FAIR removed due to earthquake, after 2004/12/26. ISSC, NTUS, MAC1 removed due to earthquake, after 2002/10/15, KOKB due to equipment change, and after 2004/07/13, TRO1 due to equipment change. We continue to update the G- and R-SINEX files based on differences between the header information and the igs.snx file. There are two sets of phase center models in use: the official IGS file and one from the US National Geodetic Survey and each week there are many reported changes due to the differences between these models.

Deconstraining AC SINEX files

The deconstraining methods for the GNAAC sinex files have remained the same as previously reported with our continued addition of translation noise to the GFZ sinex files to remove the center of mass constraint.

Most RNAAC sinex files are minimum constraint except for the NAR submission which has tight constraints on selected sites. We have numerical problems in removing these constraints and the loosely constrained versions of these sinex files that we available at gauss.geod..nrcan.cc.ca are no longer being made available. As reported in previous years we continue to have difficulty undoing the constraints being applied by the analysis centers.

Analysis of combined solutions

Our analysis of 2003-2004 combined SINEX files examines the internal consistency of these combinations and their agreement with IGb00. In figure 1 we show for each weekly combination, the RMS agreement between the IGb00 reference sites. The list and number of sites used each week is given in weekly summary. This RMS is computed from the combination of the north, east, and height differences after a translation, rotation, and scale are removed from the weekly combination. In computing the RMS, the height is down-weighted by a factor of 3, i.e., we construct a weight matrix with the heights given one-tenth the weight of the horizontal components.

In Figure 2, we show the positions of the sites in the G- and P-combinations. The time series of the position estimates can be found at http://www-gpsg.mit.edu/~fresh/MIT_IGS_AAC. The IGS weekly combination produced by Natural Resources Canada (NRCan) is updated weekly on this site. The time series from the other IGS centers shown are only updated occasionally. The statistics of the position residuals, after removal of linear trends, are given in Table 1. Analyses of the residuals do show offsets in the time series that are thought to arise from the residual effects of constraints on the solutions that cannot be completely removed. More detailed analysis of this problem is required at the moment.

We also make available Matlab based tools for the analysis of the IGS combined solution. These tools are available at http://www-gpsg.mit.edu/~tah/GGMatab. On the MIT IGS AAC web page a compressed tar file is available that contains the IGS weekly time series in a format suitable for use with these tools (http://www-gpsg.mit.edu/~tah/MIT_IGS_AAC/igsw/igsw.tar.Z)

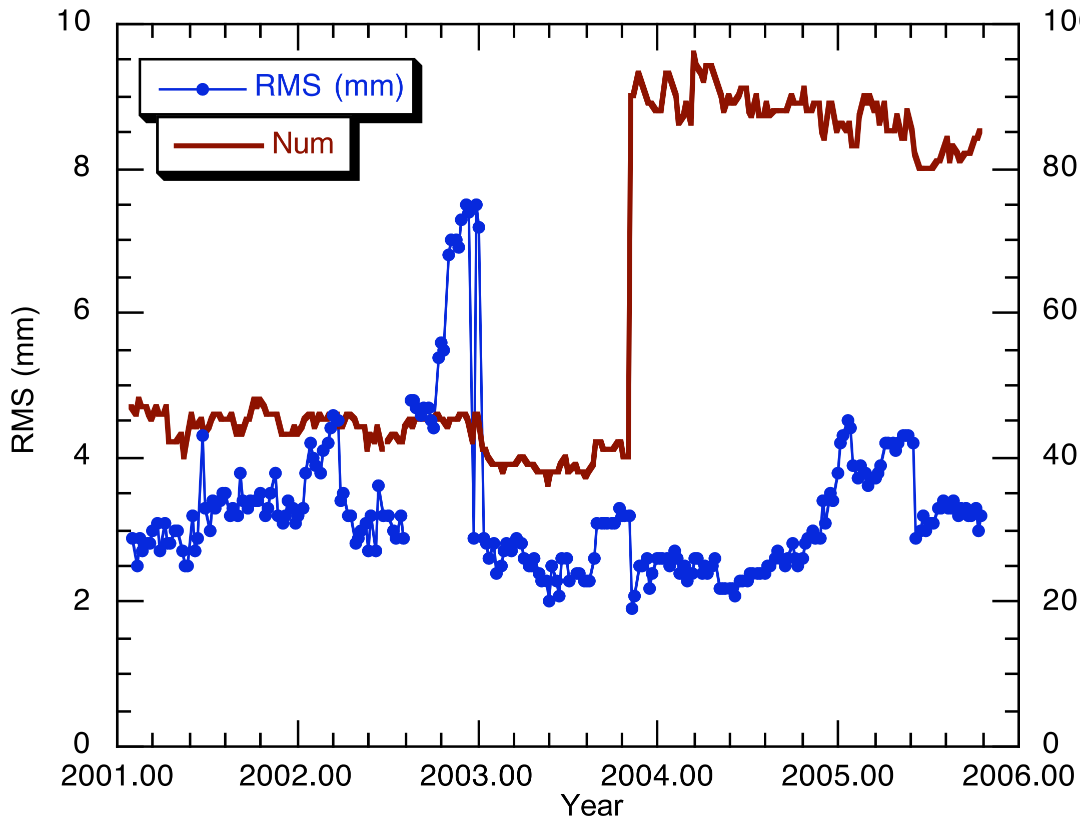

Figure 1: RMS fit of the weekly combinations to the up to 99 IGb00 reference sites (after 2003). The increase in the number of sites in late 2003 is when the 99 reference sites were adopted. The increases and decreases in the RMS fits are associated with displaced sites that were not immediately removed from the reference frame list of sites.

Table 1: Distribution of the root mean square (RMS) scatters of the position estimates after removal of a linear trend for the North, East and Height components for the G- and P-SINEX combinations. Values shown are the RMS scatters below,which 50, 70 or 90% of the sites lie. Statistics are for 2003-2004 results.

Component	G-SINEX Combination (323 sites)			P-SINEX Combination (1017 sites)		
	50 % (mm)	70% (mm)	95%(mm)	50%)mm)	70% (mm)	90% (mm)
North	1.4	1.8	3.3	1.8	2.2	4.0
East	1.5	1.8	3.5	2.1	2.5	5.4
Height	5.0	6.0	10.4	7.1	11.3	44.5

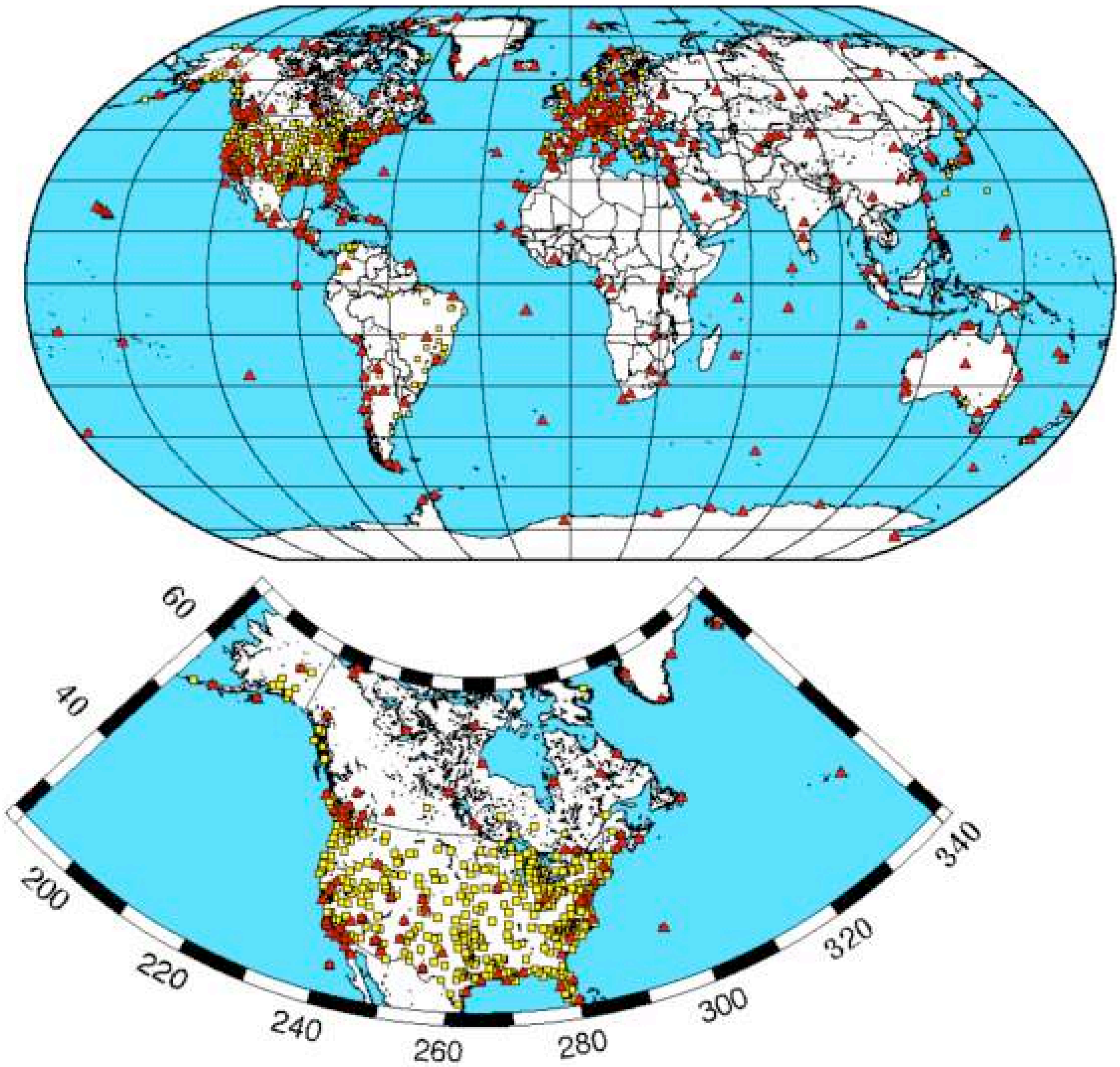

Figure 2: Global distribution of sites used more than 10 times between 2003 and 2004 in the G-SINEX (red triangles) and P-SINEX (yellow squares) combinations. There are 388sites in the G-SINEX files and 1107 sites when the G- and P-SINEX files are combined.

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Analysis and Special Projects within the EPN

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Introduction

The analysis of the observations of the EUREF GPS Permanent Network (EPN) is a continuous task. Local Analysis Centers process the daily files of dedicated sub-networks and weekly station coordinate solutions of the 16 sub-networks are combined into the official EPN solution file in the SINEX format. Improved models and software are always applied as soon as they are verified and agreed upon within the EPN partners. EUREF basically follows the IGS standards. There was a new "Special Project (SP)", called "ECGN", established beside the existing SPs for "Troposphere", "Time Series" and "EUREF-IP". The primary concern of the "European Combined Geodetic Network (ECGN)" consists in connecting the height component with the gravity determination while allowing for measuring data that are acquired in the European coastal regions and above adjacent seas. The EUREF-IP SP reported in the "Network Operations and Data Flow within the EPN" article.

Analysis Coordination

The 4th EPN Local Analysis Center (LAC) workshop was hold at the Space Research Institute, Department Satellite Geodesy, Austrian Academy of Sciences in Graz from September 18 to 19, 2003 and was an important step in the development of the EPN analysis. 28 participants from 16 nations verified the widely acceptance of the workshop, and 14 of the 16 LACs had been represented. The objective of the workshop was to review the work of the last 2 years, to discuss about participation in current and future projects, to improve the analysis strategy, and to investigate the future direction of the EPN. Thus there was the goal to develop a roadmap for the next 2 years. The 4 sessions of the workshop covered the topics (1) LACs reports, (2) EPN special projects reports, (3) processing strategies, and (4) discussion. The results of the discussion have been compiled into the minutes that are available at the EPN central bureau together with all workshop contributions and are also given in the following:

Recommendation 1: To fix the datum of the weekly EPN solutions, as well as the individual LAC solutions, the minimal constraint approach is better than the fixed-station approach. Using the present version of Bernese, it is not possible to apply this minimal constraint approach and to write the results into a SINEX file. This topic will be re-discussed when the next Bernese version will be released.
Recommendation 2: In order to evaluate the use of daily SINEX submission by the LACs, H. Habrich will invite the LACs to participate in a test campaign (~8 weeks). The final decision on the daily SINEX submission is delayed until the results of the test campaign are available and the datum definition of the sub-networks has improved.
Recommendation 3: Who is using the weekly ETRS89 solutions? Should we recommend a pre-transformation from ITRFxx to ITRF2000 before the transformation to ETRS89 to prevent the

rotation in the ETRS89 which becomes visible since the usage of ITRF2000? Discuss these topics at the next meeting of the EUREF Technical Working Group.
Recommendation 4: Contact the IERS Special Bureau for the Atmosphere and inform them about EUREFs interest for the modelling of the atmospheric loading. Other methods to improve the height component can only be implemented when using the Bernese V5.0.
Recommendation 5: Absolute receiver and satellite antenna PCVs will improve the EPN solutions. However, their implementation should be coordinated with the IGS and will therefore at least be postponed until the next IGS workshop in Berne, March 2004.
Recommendation 6: H. Habrich will invite the LACs to participate to some test computations adding GLONASS data to their sub-network solution.
Recommendation 7 - Processing Options –
Recommendation 7.1: Should we allow solving for troposphere gradients? It is to soon now to know what to do. Better is to wait and gather experience with the new Bernese software version.
Recommendation 7.2: Are there any alternatives to the weighting scheme that is presently used to create the EPN Combined Solution? H. Habrich will look into how the IGS is doing the waiting and investigate whether it can be used for the EPN combination.
Recommendation 7.3: Should we introduce satellite dependent weights, e.g., the accuracy codes as given in the IGS orbits? Presently, the use of satellite dependent weights needs further testing and should be re-discussed in the future.
Recommendation 7.4: Should we reprocess the EPN? Although a complete reprocessing of the EPN would improve the overall consistency of the time series, it is recommended to wait for a final decision on the absolute PCVs and the new Bernese V5.0, which will include new processing options that will improve the overall quality of the computations.
Recommendation 7.5: Should we use the radom-dependent receiver antenna calibration values that IGS issues into the EPN processing (20 character code not fully supported by Bernese Version 4.2)? The EPN LACs that use software other than Bernese should test the radom-dependent calibration values and inform the Analysis Coordinator about this, so that he can test for inconsistencies between the different solutions.
Recommendation 7.6: The proposal for a new LAC in Bucharest at FGB (Faculty of Geodesy Bucharest) was generally accepted. The plenum of the Workshop became convinced to favour the distribution of the EPN analysis to many European nations against the scientific aspect of a common solution. FGB will contact the EPN-CB if it is prepared to start with the analysis. After that, a sub-network will be designed.

Most of the planned actions require the new version 5 of the Bernese GPS Software that is used by 14 of the 16 LACs. Since GPS week 1303 (the last week of 2003) , the ADDNEQ2 program of the new version 5 is used to combine the sub-networks into the weekly EPN solution.

Time Series Special Project

The principal purpose of the project is the monitoring of the EPN coordinate time series in order to identify and eliminate outliers and detect offsets may present in the combined weekly EPN SINEX solutions. The monitoring is based on the so called ***raw EPN time series*** produced by C.Bruyninx and G.Carpentier at the EPNCB. The main products of the project are the periodically updated databases of outliers and offsets available at the EPNCB website. The Special Project also contributes to the realization of the ITRF2004 both on global and regional level. The station problem information concerning the IGS subset of the EPN network has been added to the IGS discontinuity sinex file.

The cumulative solutions of the EPN weekly SINEX files are computed with the CATREF software using the minimum constraint approach. Taken all station-related problems into account the so-called ***'improved'*** time series plots are created and displayed at the EPNCB website.

In the frame of the project reliable velocities and velocity uncertainities are estimated. The velocity uncertainities are estimated with the CATS software (provided by SD Williams, Proudman Oceanographic Laboratories) based on the Maximum Likelyhood Estimation approach. Our investigations confirmed that colored noise is present in the EPN time series.…

Troposphere Special Project

The main element of the EPN Special Project “Troposphere Parameter Estimation” which started its practical work in June 2001 is to produce a combined troposphere solution for all sites included in the EUREF Permanent Network. The combination includes the individual daily solutions of the 16 LACs and is performed on a weekly basis. Within the last two years the number of stations analysed routinely increased from ~162 to ~178. Almost all of the stations have been analysed by 3-5 LACs. This is a result of the rules and guidelines set up for the EPN.

Since GPS week 1203 the SP has been contributing to the IGS troposphere combination. The contribution is carried out on a strictly weekly basis with all solutions available so far. The number of common sites with one or more of the IGS ACs increased from ~45 to ~55. The mean value of the weekly mean biases of the EPN solution is + 2.7 mm ZTD. The significant biases (mean standard deviation ± 1.4 mm ZTD) have a seasonal signature with the maximum in June/July. Since there is no visible dependency on e.g. number of sites or number of contributing LACs the periodic behaviour is mutually reduced to differences in the height coordinates.

A number of analysis centres of the EPN have been involved in the COST Action 716 “Exploitation of ground-based GPS for operational numerical weather prediction and climate applications”. This project was finished with the final report in April 2004. The combination of the individual solutions in post-processing mode has been as an example for climate monitoring. Moreover, six LACS of EPN (ASI, BKG, GOP, LPT, NKG, ROB) have been contributing to the near-real time application on an operational basis. The successor of the COST action is “The EUMETNET GPS Water Vapour Programme” (E-VGAP) of EUMETNET (which is the Network of European Meteorological Services), starting in early 2005.

ECGN Special Project

The ECGN is a European Network for the integration of time series of GNSS observations, gravity field related observations and parameters (precise levelling, tide gauge records, gravity observations, earth and ocean tides), and supplementary information (meteorological parameters, surrounding information of the stations, e.g. eccentricities and ground water level). The objectives of ECGN as an integrated European Reference System for Spatial Reference and Gravity are the maintenance of the terrestrial reference system with long-term stability for Europe especially in the height component, in-situ combination of geometric positioning (GPS) with physical height and other Earth gravity parameters at 1 cm accuracy level and the modelling of influences of time depended parameters of the solid Earth of the Earth gravity field, the atmosphere, the oceans, the hydrosphere for different applications of positioning.

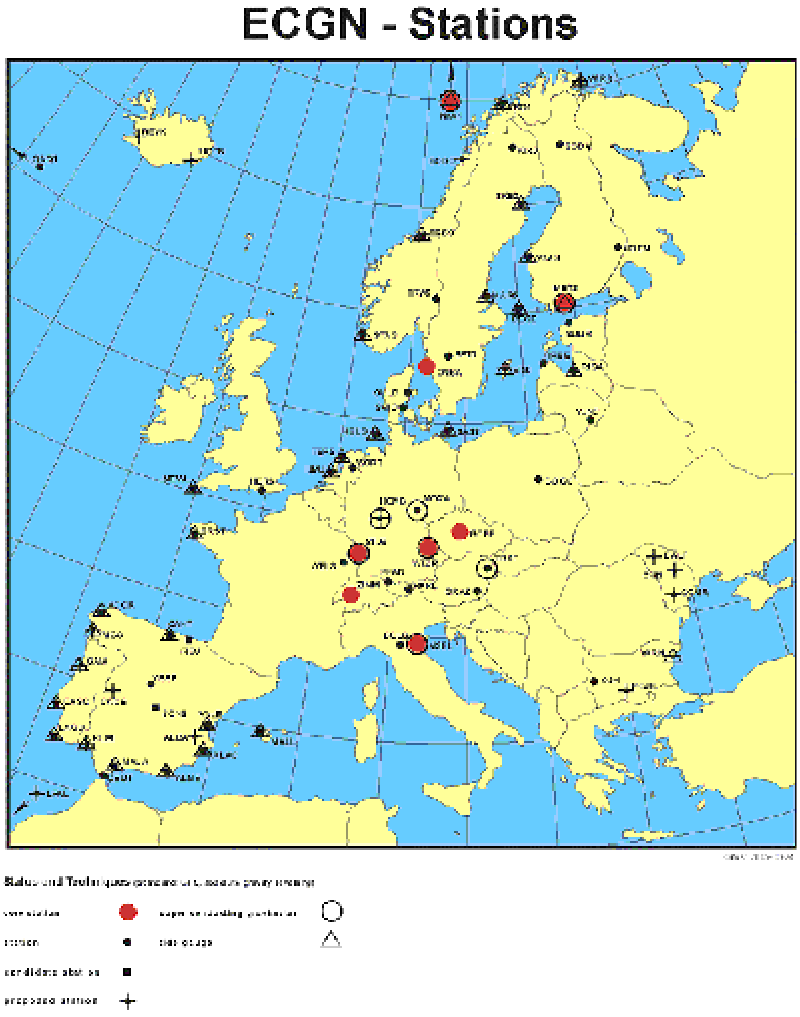
In order to ensure the long-time stability of the terrestrial reference system with an accuracy of 10^{-9} in the global and continental scale, the interactions between different time dependent influences of the system Earth to the terrestrial reference system and the related observation have to be considered in the evaluation models. The ECGN integrates the spatial and height reference system into the Earth gravity field parameter estimation. This is in agreement with the IAG project of the Global Geodetic Observation System (GGOS).

The ECGN stations have the standard observation techniques:

- GNSS (GPS/GLONASS, GALILEO) , permanent,
- gravity (super-conducting gravimeter and/or absolute gravimeter) , permanent or repeated,
- levelling connections to the UELN/EVRS , repeated,
- meteorological parameters , permanent.

Proposed were 74 Stations in 21 European countries. The ECGN working group agreed on criteria for the four station categories:

- core station - if the criteria of ECGN are fulfilled and additional special conditions exist like fundamental station/observatory and/or measurements of a Super Conducting Gravimeter
- station ok - if criteria are fulfilled at present or will be fulfilled in the future or are planned
- candidate station - few of the criteria are not fulfilled (e.g. permanent GPS not yet realised)
- proposed station - at present several criteria are not fulfilled and not likely in the future.



Considering the situation of the proposed network, 8 stations were selected as core stations, 42 have the “ok”-status. As result we have in summary 50 ECGN stations. 7 Stations were identified as candidates and 17 proposed stations. All ECGN stations are part of the European GPS Permanent Network EPN. The ECGN Working Group is preparing standards for an absolute gravity data base. The model of a decentralized ECGN data bank was favoured. That means, that each station owner and each instrument owner should provide the necessary information in a common format on their own web page.

GSI RNAAC Technical Report 2003-2004

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Introduction and Overview

Since 1996, Geographical Survey Institute (GSI) has been contributing as RNAAC. The network consists of 9 IGS global sites (Fig. 1a) and 7 domestic GPS sites (Fig. 1b). The result SINEX files are submitted to the Crustal Dynamics Data Information System (CDDIS).

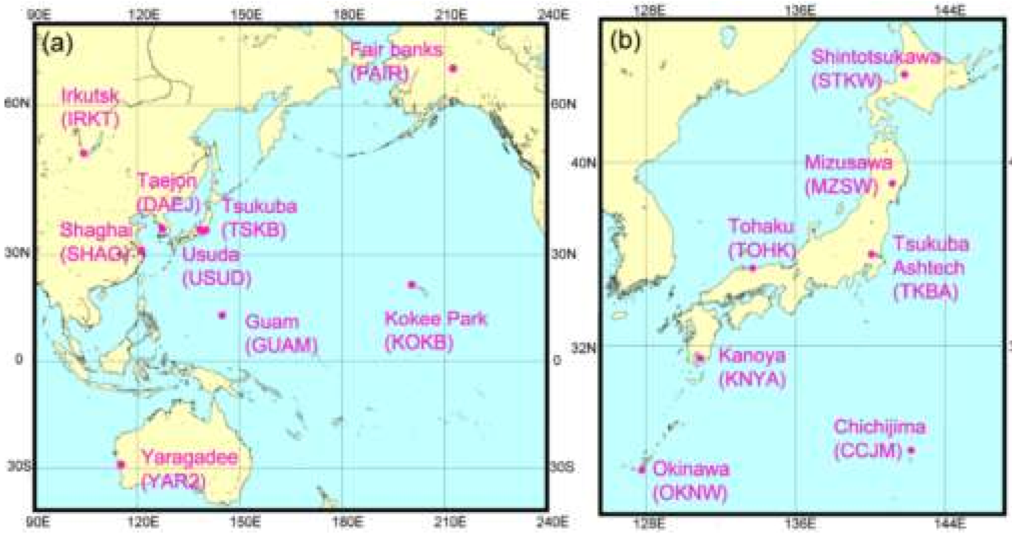

Figure 1. GPS stations for GSI RNAAC (a) IGS global sites (b) domestic sites

Outline of Data Processing

Coordinates and covariance are generated in daily basis using GAMIT version 10.07 and they are combined with GLOBK version 5.06 to generate weekly SINEX with loose constraint. The software was upgraded from GAMIT 9.95 /GLOBK 5.04 in GPS week 1235.

The specification of the analysis is as follows;

IGS final orbits and EOPs are applied

Elevation cut-off angle of 20°

Data rate of 30 secs for single-day adjustments

Tropospheric zenith delays are estimated every 3 hours

IGS antenna phase center variation model (IGS01) is applied

Station coordinates estimated, applying a priori sigma of ~10m

Reference Frame was upgraded from ITRF97 to ITRF2000 on the first day of GPS week 1238.

Current State

The standard deviation of GSI RNAAC weekly solution is shown in Fig. 2.

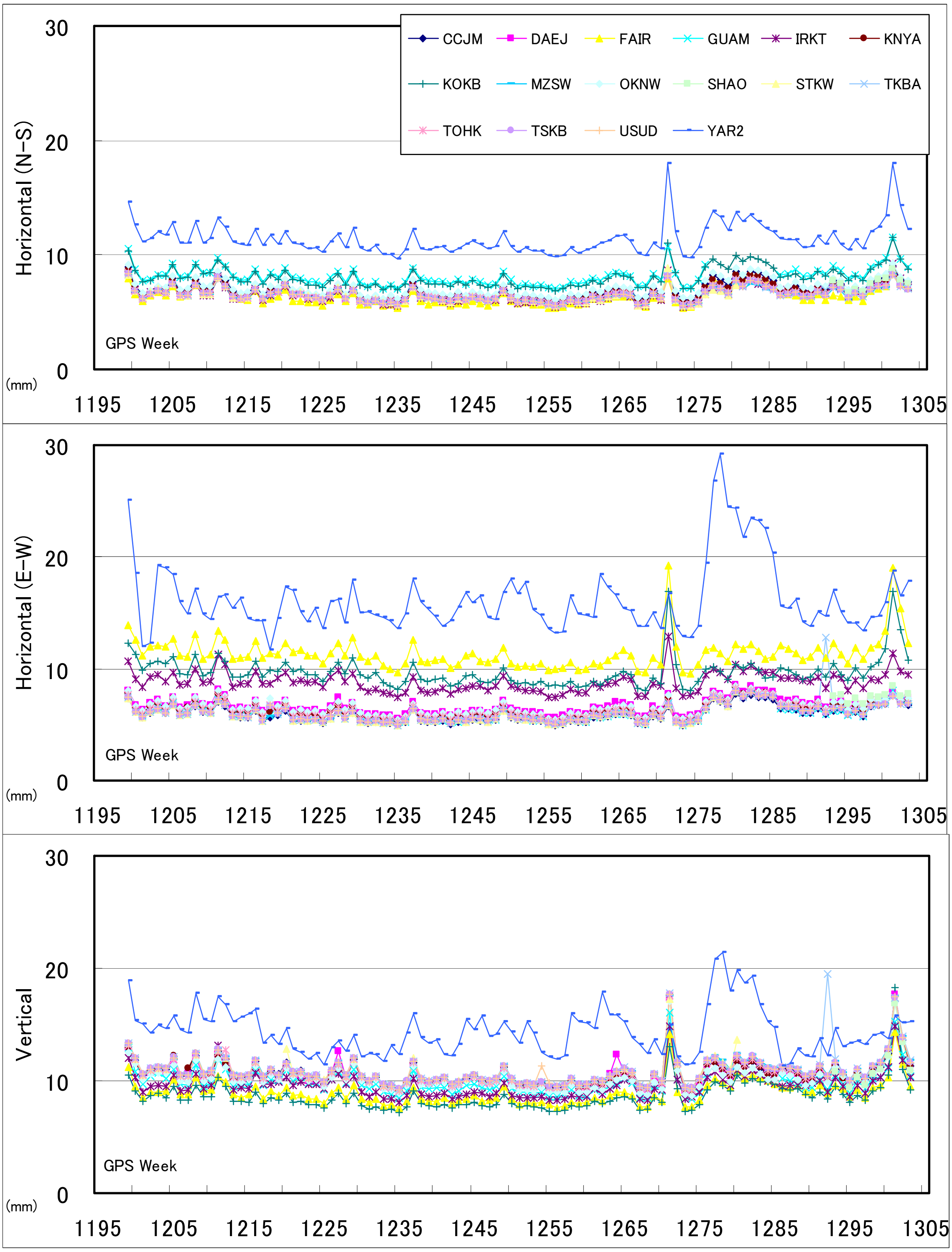

Figure 2.Standard Deviation of GSI RNAAC weekly solution

Annual Report 2003/2004 of IGS RNAAC SIR

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Introduction

This report presents the status of the IGS RNAAC SIR network and recent activities. Besides the routine weekly delivery of normal equations for the permanent SIRGAS network, an accumulated solution (DGF04P01S) for coordinates and velocities has been computed.

Station Network

The number of IGS and regional station included in RNAAC SIR increased remarkably during the last years. In 2003 and 2004 the active network consisted of 73 stations (42 global and 31 regional, see figure 1).

Fig. 1: IGS RNAAC SIR network

Solutions

In addition to the weekly loosely constrained normal equations submitted to the IGS Global Data Centres, DGFI produces weekly fixed coordinate solutions of the whole network as a support to the South American countries for use in their national reference frames and regional projects. These solutions are available at the DGFI public server in the directory

ftp://www.dgfi.badw-muenchen.de/pub/gps/DGF

Another combined solution for the kinematics of the network was performed end of 2004. This new solution DGF04P01S covers the time period June 30, 1996 to July 31, 2004. It is referred to the IGS solution IGb00 by selecting 9 stations as fiducials for the datum realisation (see figure 1). The reference epoch is 2003.0.

Figures 2 and 3 show the horizontal and vertical velocities of all stations with at least one year of observations. The numerical values of this solution are available at

ftp://www.dgfi.badw-muenchen.de/pub/gps/DGF/DGF04P01.SNX

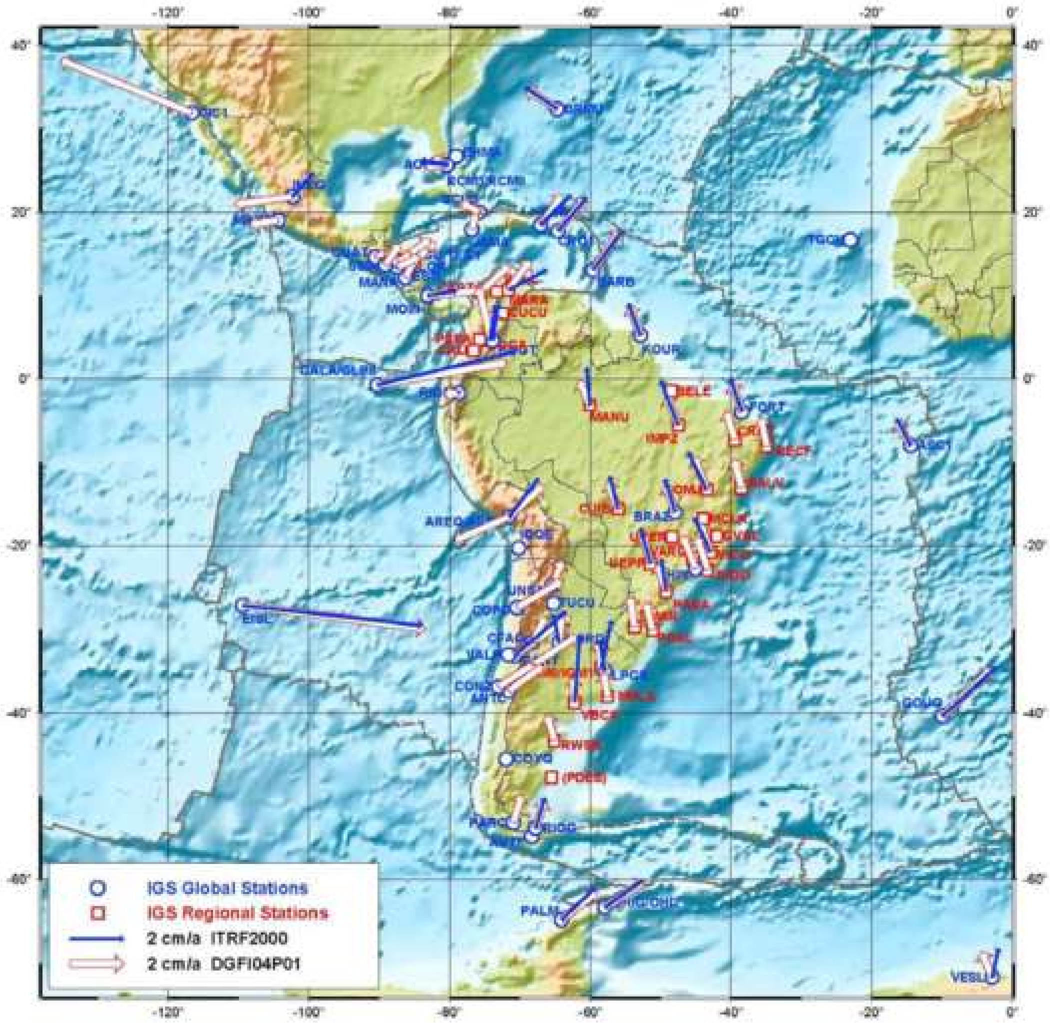

Fig. 2: Horizontal velocities of IGS RNAAC SIR stations and comparison with ITRF2000

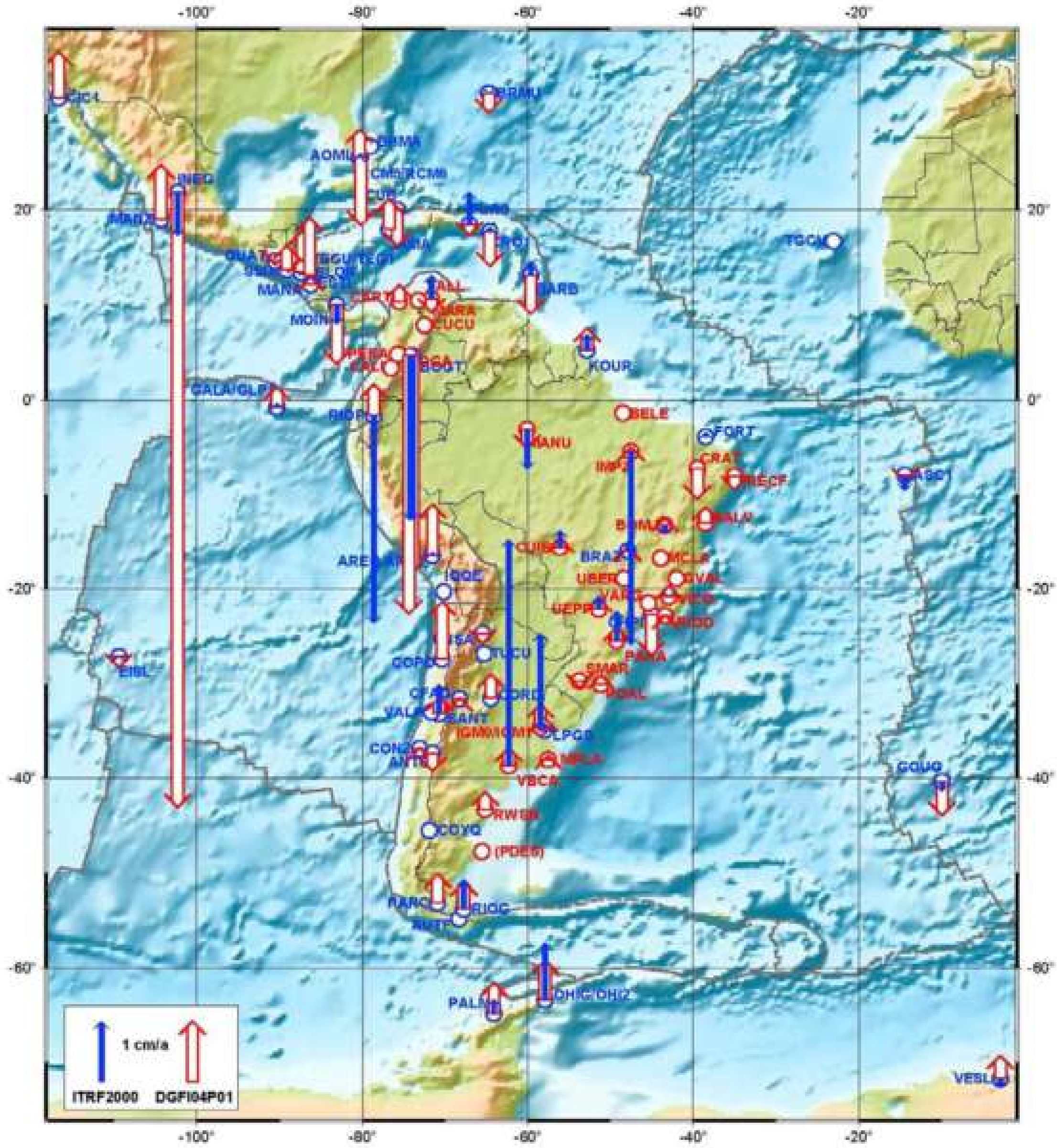

Fig. 3: Vertical velocities of IGS RNAAC SIR stations and comparison with ITRF2000

Conclusion

The long observation period of more than eight years for most of the IGS RNAAC SIR stations allows the estimation of reliable velocities for much more stations than in the previous solutions. From now on a new station coordinate and velocity solution will be estimated each year.

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SPECTRAL CHARACTERISTICS OF THE MEASUREMENT OF STATION MOTION WITH GPS

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Abstract. Time series of IGS station coordinates are analysed to investigate the spectral content of the observed non-linear station motion of 189 well observed IGS stations over 1999-2005. The statistical quantities derived include medium term stability and annual signatures in the time signal eigenspace and in the local frame, scaling factors of the original coordinates uncertainties, stability indices, and various flags and criteria for the selection of a reference network suitable for achieving long term consistency. The signal is dominated by the height component, in both the annual band and long term noise. In about 80% of the stations the non linear, non seasonal motion has a flicker noise spectrum in the horizontal as well as in the vertical directions. The remaining 20% have a white noise spectrum.

1. Introduction

We present hereafter a set of statistical investigations and we propose diagnostics concerning the spectral content of time series of coordinates of a set of IGS stations using time series of station coordinates. The major signature in time series of station coordinates is usually modelled as a tri-dimensional linear drift. The horizontal component is mostly related to the tectonic plate motion, while the Up component is assumed to reflect local uplift or subsidence. The remaining component may be interpreted as noise related to local geophysical phenomena, instrumentation, or to the analysis strategies and modelling. The hypothesis of linear motion is also a key one in most uses of space-geodetic positioning. For this reason, our study is focusing on time series of coordinate residuals relative to linear motion of the station.

The analysis approach is described by Le Bail (2005). The analysis is made in both the local reference frame and the eigenspace derived from Principal Component Analysis in the time domain. The spectral behaviour of the series is characterised by means of the Allan variance. A convenient and rigorous way to relate the Allan variance of a signal to its spectrum is the interpretation of the Allan graph, which gives the changes of the Allan variance for increasing values of the sampling time τ. In logarithmic scales, slopes -1, 0 and +1 correspond respectively to white noise, flicker noise and random walk. To avoid biasing due to the presence of seasonal variations, the Allan graph slopes may be computed on time series corrected for an annual term.

The data analysed are sets of time series of local station East (longitude), North (latitude) and Up (vertical) coordinates downloaded on July 12, 2005 from the anonymous ftp macs.geod.nrcan.gc.ca/-pub/requests/sinex/coord_r/'station'_igs.utm. These data are available over the time span 1999.0 to the present. The data in this directory are corrected for all discontinuities and defects known. According to Ferland (2005), they are close to the data submitted for the ITRF2004 implementation.

2. Data analysis

The data analysis is performed for each station individually. The general conditions of the analysis are the following.

- Data: time series E, N, U station coordinates at one-week intervals.
- Station primary selection: the station is selected for analysis if it satisfies the following conditions:
    - Series duration longer than 3.1 years.
    - Largest data gap spanning less than 400 days.
    - Percentage of edited data under 30% in all three E, N, U directions.
- Station secondary selection. Some stations that pass the above selection still have a data configuration that may weaken the analysis. Their results are flagged in the outputs and they are not considered in the network statistics. The conditions to be satisfied for this secondary selection are as follows.
    - Largest data gap spanning less than 200 days.
    - Number of yearly averages larger than or equal to 4.
- Data editing: a linear trend and an annual term are first fitted by weighted least-squares in the original E, N, U series. Values with postfit residuals > 3 σ are deweighted.
- Post-seismic data: the post-seismic data at Arequipa (23.06.2001) and Fairbanks (03.11.2002) are ignored.

The first part of the analysis sequence aims at finding out the spectral characteristics of the series. The data are replaced by their residuals with respect to a weighted least-square linear trend estimated separately in the E, N, and U directions. The data uncertainties are kept, except in the case of edited data. Principal Component Analysis in the time domain of the 3D series of residuals is performed. The resulting time series are referred to has PCT_i, i = 1,3. The annual components in the ENU and PCT coordinate systems are estimated by weighted least squares. Allan variance analysis of the series of residuals less the above annual component is performed in the ENU and PCT coordinate systems, for sampling times ranging from the input data sampling to about 1/3 of the data set length. If more than four estimates of the Allan variance are obtained, the linear slope of log(variance) as a function of log(sampling time) is estimated by weighted least squares. The slopes and their interpretation in terms of spectral signature are a part of the software outputs. The slopes in the PCT coordinate system enter into the construction of the stability index.

The second part of the analysis sequence aims at qualifying the longer term stability of the time series. It is based on the Allan variance analysis of data brought to one-year intervals. The one year sampling is a compromise that insures on the one hand the filtering of high frequency errors, and on the other hand the construction of time series with enough epochs. The one year re-sampling has also interesting properties with respect to annual signatures that are often present, as will be seen in the results. Two statistical parameters are derived:

- A scale factor of the original data uncertainties, defined as the ratio of the standard deviation of the yearly means to their average rms formal uncertainties. Larger scale factors indicate larger underestimation of the uncertainties associated with the data. Note that the standard deviation of the yearly averages is insensitive to the presence of an annual signal.

- A stability index, derived from three pairs of partial indices, one for each of the three PCTs, as follows.
  - The first three partial indices are defined as the normalised value of the Allan standard deviation for a one-year sampling time (Asd_i, i = 1,3) of the time series of residuals to linear motion in their time eigenspace. In other terms, each ASd_i is obtained by dividing the one-year Allan standard deviation of PCT1, resp. PCT2, and PCT3 by a conventional value α_ι : α_1 = 2.5 mm, α_2 = 1.5 mm, and α_3 = 0.5 mm. To give an example a 5 mm Allan standard deviation for PCT1 will produce a partial index ASd_1 equal to 2. These numbers were empirically chosen to allow a unique definition of the stability index for the four global geodetic techniques, VLBI, SLR, GPS, and DORIS.
  - The second set of three partial indices, ($Arate_i$, i = 1,3) is derived from the slopes of the Allan graphs for the series of continuous residuals in the PCT coordinate system. It is equal to the value of the slope +1, i.e. 0 in the case of white noise, and 1 in the case of flicker noise.
  - The three pairs of partial indices are combined as

$$\frac{1}{100}\sum_{i=1}^{3}(ASd_i + Arate_i)\times Pc_i$$

Where (Pc_i, i = 1,3) are the percentages of variance explained by PCT1, PCT2 and PCT3, respectively (by definition, the sum of the three percentages is equal to 100).

The two components of the stability index reflect both the stability in the one-year time frame and the spectral power law, which represents the stability expectation. Most stability indices range from 1 (most stable) through about 4 (least stable) for all four space-geodetic techniques. With the values chosen for the α_i coefficients, the major contribution to the stability index comes from the signal Allan standard deviation. The second set of partial indices degrade the stability index only in the case of flicker noise.

3. Results

Table 1 lists general statistics for the 189 most observed stations in the data available. The contents of the table is as follows.

- **DOMES No**: DOMES Number of the station.
- **Start End**: Start and end dates of the data span, in years (first two digits of year omitted).
- **#**: number of yearly averages. Flagged by ‘#’ if smaller than 4.
- **%Ms**: Percentage of missing values in the original series. Flagged by ‘#’ if the largest data gap spans more than 200 days.
- **PCT1:** for PCT_1, percentage of signal variance that it explains, Allan standard deviation for a one-year sampling time in millimetres, and noise spectrum. ‘Wh’ stands for white noise, ‘Fl’ for flicker noise.
- **1-yr All_StDv & Noise** (E, N, U): Allan standard deviation for the one-year sampling time of the series in the ENU coordinate system, in millimetres, and noise spectrum.
- **Scale factor**: Scale factor based on the Allan variance for the one-year sampling time. Large scale factors indicate larger underestimation of the formal uncertainties.

- **Sta. Index**: Stability index. The most stable series have the lowest stability index.

Figure 1 gives a global view of the statistics of Table 1. The figure includes four horizontal zones. The three top zones concern the 138 best observed stations, i.e., those not flagged in Table 1. They are split into four columns, corresponding to the first PCT (PCT1) and its projection on the E, N, U directions, respectively. A fourth horizontal zone is dedicated to the scale factor of uncertainties and the stability index of the 160 stations.

Top zone 1: Histograms of the one-year Allan standard deviations in millimetres, with the histograms of explained variance (%Var) inserted for PCT1.

Top zone 2: Histograms of the amplitudes of the annual components in millimetres, with the histograms of their normalised values (amplitude divided by uncertainty) inserted for PCT1, with a vertical bar at value 3.

Top zone 3: Two-dimensional graphs showing for each station the one-year Allan standard deviation (with error bars) as a function of the slope of its Allan graph. The vertical bands correspond to white noise ('Wh') and flicker noise ('Fl') signatures.

Bottom zone : Relationship between the scale factor of uncertainties and the stability index. The colour code is as follows. Blue: well observed stations; pink: data span shorter than four years; green: largest data gap longer than 200 days.

The IGS maintains a file giving lists of confirmed and probable discontinuities in the station time series at anonymous ftp macs.geod.nrcan.gc.ca/pub/requests/sinex/discontinuities. The version of the file used here was downloaded on June 23, 2005. The expected influence of such events on the Allan variance analysis depends on the size of the discontinuity. Small values should impact the short term response of the test, and large values should impact its long term response. Figure 2 shows the distribution of the type of noise, defined by the slope of the Allan variance graph of the first principal component in the time domain of the non linear, non seasonal station motion, in connection with the existence of confirmed or probable discontinuities. In Fig. 2a known discontinuities were corrected and series generally checked. In Fig.2b the discontinuities were not corrected. The correction of known discontinuities slightly improves the proportion of white noise.

Table 1. Stability estimators for 189 IGS stations, 1995.0-2005.4

DOMES No	Stn	Start	End	#	%Ms	PCT1 Expl.	ASdv mm	Ns	1-yr All_StDv, Noise East mm	Ns	North mm	Ns	Up mm	Ns	Scal fact	Stb ind
40129M003	ALBH	96.1	05.4	9	1	89%	2.7	Fl	1.4	Fl	1.2	Fl	2.6	Fl	2.67	2.2
40104M002	ALGO	96.1	05.4	9	2	76%	2.6	Fl	.8	Fl	1.6	Fl	2.5	Fl	3.69	2.0
50137M001	ALIC	98.5	05.4	6	2	88%	3.9	Fl	1.2	Fl	.5	Fl	3.7	Fl	3.30	2.2
40472S004	AMC2	98.8	05.4	6	1	86%	2.0	Fl	.6	Wh	1.8	Fl	1.7	Fl	2.12	1.9
20805M002	ANKR	96.1	05.4	9	19	76%	3.6	Fl	2.7	Fl	2.4	Fl	2.6	Fl	1.88	2.1
49914S001	AOML	98.2	04.3	6	3	75%	2.5	Wh	1.2	Wh	1.2	Fl	2.2	Fl	1.85	1.4
42202M005	AREQ	95.9	01.5	5	12	82%	3.8	Wh	3.6	Fl	1.7	Fl	1.7	Fl	2.31	1.8
12362M001	ARTU	99.7	05.4	5	1	69%	2.2	Fl	1.1	Fl	1.2	Fl	1.9	Fl	2.98	1.5
30602M001	ASC1	96.3	05.3	8	15#	76%	1.8	Wh	1.4	Wh	1.0	Fl	1.9	Fl	1.04	1.3
50209M001	AUCK	96.1	05.4	9	3	66%	2.3	Fl	1.4	Fl	1.3	Fl	2.3	Fl	1.71	1.9
24901M002	BAHR	96.6	05.4	8	4	76%	2.3	Fl	2.1	Fl	1.2	Fl	1.1	Wh	2.32	1.6
23101M002	BAKO	98.3	05.4	7	22	90%	5.8	Wh	1.9	Wh	1.7	Wh	6.1	Wh	1.46	2.6
49927S001	BARH	01.3	05.4	4	25#	87%	2.9	Wh	.2	Fl	2.9	Wh	1.5	Wh	1.24	1.4
12363M001	BILI	99.7	05.4	5	20#	90%	2.0	Wh	.5	Fl	1.0	Fl	1.7	Wh	2.02	1.0
	BISH	96.5	05.4	8	20	85%	3.7	Fl	1.1	Wh	1.6	Fl	3.6	Fl	1.59	2.2
21601M001	BJFS	99.9	05.4	5	5	91%	4.1	Fl	1.1	Fl	1.4	Fl	4.1	Fl	4.28	2.6
41901M001	BOGT	96.1	05.4	9	44#	57%	3.2	Wh	1.2	Wh	1.7	Wh	3.0	Wh	1.07	1.4
12205M002	BOR1	96.1	05.4	9	1	70%	2.9	Fl	1.2	Fl	1.0	Fl	2.9	Fl	2.23	1.8
41606M001	BRAZ	96.7	05.4	8	46#	75%	8.1	Wh	2.8	Wh	2.2	Wh	8.0	Wh	.35	3.0
42501S004	BRMU	96.0	05.4	9	4	71%	2.9	Fl	.6	Fl	2.2	Fl	2.8	Fl	2.55	2.0
13101M004	BRUS	96.1	05.4	9	1	53%	2.0	Fl	1.2	Fl	1.5	Fl	1.6	Fl	1.54	1.6
11401M001	BUCU	99.6	05.4	5	32#	95%	4.0	Wh	.9	Wh	1.2	Wh	3.8	Wh	2.43	2.0
12725M003	CAGL	96.9	05.4	8	19#	98%	6.7	Fl	.9	Fl	.8	Wh	6.7	Fl	3.44	3.5
66011M001	CAS1	96.1	05.4	9	6	70%	3.4	Fl	1.1	Fl	1.1	Fl	3.4	Fl	2.09	2.0
	CAVA	01.7	05.4	3#	3	96%	3.1	Wh	.8	Wh	1.4	Wh	2.7	Fl	2.02	1.6
50138M001	CEDU	98.6	05.4	6	1	84%	4.1	Fl	1.5	Fl	.8	Fl	4.1	Fl	3.09	2.4
50207M001	CHAT	96.1	05.4	9	2	73%	3.1	Fl	.9	Fl	1.4	Fl	3.1	Fl	2.53	2.1
40128M002	CHUR	96.1	05.4	9	3	98%	3.6	Fl	.8	Fl	.7	Fl	3.6	Fl	2.43	2.2
40508M002	CIC1	99.3	05.4	6	12	76%	3.1	Fl	1.4	Wh	1.7	Fl	3.3	Fl	1.22	2.1
50127M001	COCO	96.5	05.4	8	5	95%	9.2	Fl	9.0	Fl	2.4	Fl	2.6	Fl	6.58	4.5
41511M001	CORD	99.8	05.4	5	37#	95%	5.3	Wh	1.1	Wh	.7	Wh	5.3	Wh	2.50	2.4
43201M001	CRO1	96.1	05.1	8	1	72%	4.1	Fl	1.5	Fl	1.8	Fl	4.0	Fl	2.10	2.4
23902M002	DAEJ	99.2	05.4	6	4	41%	1.0	Wh	1.1	Fl	.8	Fl	1.1	Wh	.85	1.1
50134M001	DARW	98.5	05.4	6	13	89%	4.2	Wh	.6	Wh	.9	Fl	4.2	Wh	3.24	1.9
66010M001	DAV1	96.0	05.4	9	10	74%	2.1	Wh	.9	Wh	1.0	Fl	2.4	Wh	1.26	1.3
30802M001	DGAR	96.4	05.4	8	26#	84%	2.0	Wh	1.5	Wh	1.2	Wh	1.0	Wh	.89	.8
20710S001	DRAG	00.2	05.4	5	28	66%	1.6	Wh	1.2	Wh	2.0	Wh	1.2	Wh	.81	1.3
40105M002	DRAO	96.0	05.4	9	1	70%	1.8	Fl	1.0	Fl	1.5	Fl	1.6	Fl	2.11	1.6
40137M001	DUBO	97.0	05.4	8	9	76%	3.0	Fl	.9	Fl	1.9	Fl	2.9	Fl	2.23	2.1
41703M003	EISL	96.1	03.8	7	13#	66%	2.1	Wh	1.5	Wh	1.5	Wh	2.5	Wh	1.06	1.3
20706M001	ELAT	97.7	05.4	7	49#	93%	4.0	Wh	1.2	Wh	.9	Wh	3.9	Wh	1.03	1.9
40408M001	FAIR	96.1	02.8	6	3	91%	2.8	Fl	.9	Fl	1.3	Wh	2.8	Fl	3.07	2.1
40135M001	FLIN	96.5	05.4	8	0	65%	1.6	Fl	.6	Fl	1.3	Fl	1.4	Fl	1.27	1.5
41602M001	FORT	96.0	05.4	9	4	72%	2.6	Wh	1.6	Fl	1.3	Fl	2.5	Fl	1.53	1.7
42005M001	GALA	96.7	02.9	6	37#	93%	2.4	Wh	1.2	Wh	1.7	Wh	2.1	Wh	.52	1.3
12356M001	GLSV	98.3	05.4	7	5	76%	1.5	Fl	.5	Wh	.8	Wh	1.5	Fl	1.25	1.1
40451M123	GODE	96.1	05.4	9	1	76%	2.9	Fl	1.0	Fl	1.2	Fl	2.9	Fl	1.80	2.0
40405S031	GOLD	96.1	05.4	9	0	77%	3.9	Fl	1.9	Fl	1.8	Fl	3.7	Fl	4.41	2.7
11502M002	GOPE	96.1	05.4	9	3	84%	3.1	Fl	1.2	Fl	1.7	Fl	3.1	Fl	1.96	2.0
30608M001	GOUG	98.7	05.4	6	21	97%	6.0	Wh	1.7	Wh	.8	Wh	5.9	Wh	2.93	2.7
10002M006	GRAS	96.1	05.4	9	11	70%	2.6	Fl	1.1	Fl	1.1	Fl	2.5	Fl	1.19	1.6
11001M002	GRAZ	96.1	05.3	9	3	84%	3.1	Fl	.7	Fl	1.2	Fl	3.1	Fl	2.60	1.9
50501M002	GUAM	96.1	05.4	9	5	77%	4.4	Fl	2.0	Fl	4.1	Fl	2.9	Fl	3.07	2.8
40901S001	GUAT	00.8	05.4	4	5	90%	2.0	Fl	1.1	Fl	1.7	Fl	.9	Wh	1.64	1.5
30302M009	HARB	00.9	05.4	4	9	63%	2.1	Fl	1.4	Fl	1.8	Wh	2.5	Fl	2.31	1.8
13212M007	HERS	96.1	05.4	9	22#	88%	4.5	Wh	2.9	Fl	1.7	Fl	3.8	Wh	1.30	2.3

11006S003	HFLK	98.2	05.4	7	37#	82%	3.9	Wh	1.2	Wh	1.5	Wh	3.9	Wh	1.35	1.6
50116M004	HOB2	96.2	05.4	9	8	73%	2.7	Fl	1.7	Fl	.8	Fl	2.7	Fl	1.73	1.8
10204M002	HOFN	97.8	05.4	7	1	99%	10.3	Fl	.6	Fl	.9	Fl	10.3	Fl	9.06	5.5
40130M001	HOLB	98.2	05.4	7	33#	97%	6.4	Wh	.5	Wh	1.3	Wh	6.3	Wh	2.12	2.8
30302M004	HRAO	96.8	05.4	8	14#	67%	1.8	Wh	.8	Wh	1.5	Wh	2.1	Wh	1.13	1.2
40150M001	INVK	01.9	05.4	3#	1	98%	9.0	Fl	1.5	Fl	1.2	Fl	8.8	Fl	10.09	4.8
12313M001	IRKT	96.0	05.4	9	4	75%	2.4	Fl	1.4	Fl	.9	Fl	2.4	Fl	2.22	1.8

Table 1 (Cont.). Stability estimators for 189 IGS stations, 1995.0-2005.4

DOMES No	Stn	Start	End	#	%Ms	PCT1 Expl.	PCT1 ASdv mm	Ns	1-yr All_StDv East mm	Noise	North mm	Noise	Up mm	Noise	Scal fact	Stb ind
50136M001	JAB1	98.8	05.4	6	31#	76%	6.2	Wh	.6	Wh	3.7	Fl	5.7	Wh	3.26	2.8
42601S001	JAMA	99.9	03.7	3#	10	88%	3.6	Fl	1.5	Fl	2.0	Fl	2.7	Fl	2.38	2.0
12204M001	JOZE	96.1	05.4	9	2	73%	3.3	Fl	.8	Fl	1.1	Wh	3.3	Fl	2.04	1.9
40400M007	JPLM	96.1	05.4	9	1	70%	1.2	Fl	.9	Fl	.8	Fl	1.2	Fl	.86	1.3
50139M001	KARR	98.5	05.4	6	5	69%	1.6	Fl	.9	Wh	1.2	Wh	1.3	Fl	1.21	1.1
43005M001	KELY	96.1	05.4	9	4	98%	9.5	Fl	.5	Wh	1.5	Fl	9.5	Fl	6.38	4.9
91201M002	KERG	96.1	05.4	9	7	60%	2.2	Wh	.8	Wh	1.5	Fl	2.2	Wh	1.57	1.3
21704S006	KGN0	02.2	05.4	3#	6	93%	2.0	Fl	.0	Fl	.7	Fl	1.9	Fl	1.20	1.4
10403M002	KIRU	96.1	05.4	9	4	86%	3.1	Fl	1.4	Fl	1.1	Fl	3.0	Fl	2.00	1.9
12334M001	KIT3	96.1	05.4	9	26	82%	3.9	Wh	1.0	Wh	1.1	Wh	3.9	Wh	2.42	1.7
40419S003	KODK	00.3	05.0	4	26#	97%	5.6	Fl	4.3	Fl	1.9	Wh	3.1	Fl	3.58	2.9
40424M004	KOKB	96.0	05.4	9	5	94%	9.3	Fl	4.5	Fl	7.7	Fl	3.3	Fl	9.84	4.8
13504M003	KOSG	96.1	05.4	9	3	62%	1.9	Fl	1.1	Fl	1.9	Fl	1.4	Fl	2.40	1.7
97301M210	KOUR	95.7	05.4	9	11	56%	1.8	Wh	.9	Wh	1.2	Fl	2.0	Wh	.79	1.2
12349M002	KSTU	97.7	04.7	7	28	86%	5.7	Wh	1.6	Fl	1.2	Wh	5.7	Wh	3.82	2.6
21609M001	KUNM	98.9	05.4	6	6	98%	5.3	Fl	.6	Fl	.8	Fl	5.3	Fl	2.70	2.9
50506M001	KWJ1	96.2	02.6	6	16	91%	3.9	Wh	1.5	Wh	1.2	Wh	3.6	Wh	1.72	1.8
51002M001	LAE1	01.3	05.4	4	27	76%	2.2	Wh	.7	Wh	2.6	Wh	2.0	Wh	1.96	1.3
12209M001	LAMA	96.1	05.4	9	7	98%	4.2	Fl	.9	Fl	1.3	Fl	4.0	Fl	2.94	2.4
21613M001	LHAS	96.8	05.4	8	14	90%	3.9	Fl	1.0	Fl	1.7	Fl	3.9	Fl	2.91	2.3
41510M001	LPGS	95.9	05.4	9	12	89%	5.1	Fl	1.6	Fl	1.3	Fl	4.9	Fl	2.92	2.5
50135M001	MAC1	96.1	05.4	9	7	78%	1.5	Fl	1.3	Fl	1.5	Fl	1.3	Fl	1.23	1.4
13407S012	MADR	96.1	05.4	9	14	81%	5.3	Fl	.8	Fl	3.0	Fl	5.3	Fl	3.44	2.8
12354M001	MAG0	98.2	05.4	7	8	81%	2.5	Fl	1.7	Fl	1.0	Fl	2.3	Fl	2.54	1.9
33201M001	MALI	96.1	05.4	9	6	88%	4.8	Fl	2.9	Fl	2.0	Fl	3.7	Fl	2.43	2.7
41201S001	MANA	00.5	05.4	4	2	90%	2.8	Fl	1.1	Fl	2.7	Fl	.4	Fl	1.85	1.8
31303M002	MAS1	96.0	05.4	9	6	68%	1.7	Fl	.4	Fl	1.3	Fl	1.9	Fl	1.65	1.5
12734M008	MATE	95.7	05.4	9	7	56%	2.3	Fl	1.3	Fl	1.2	Fl	2.4	Fl	2.02	1.9
66004M001	MAW1	98.5	05.4	6	5	60%	1.5	Wh	1.1	Fl	1.4	Fl	1.7	Wh	1.24	1.2
66001M003	MCM4	96.1	05.4	9	3	91%	5.4	Fl	1.7	Fl	1.0	Fl	5.4	Fl	3.30	2.8
40442M012	MDO1	95.9	05.4	9	3	85%	2.7	Fl	.9	Fl	1.7	Fl	2.7	Fl	2.23	2.0
12711M003	MEDI	98.2	05.4	7	5	66%	2.1	Fl	.4	Wh	1.3	Fl	2.2	Fl	1.69	1.6
10503S011	METS	95.9	05.4	9	5	76%	1.7	Wh	.7	Fl	1.0	Fl	1.7	Wh	1.48	1.2
21702M002	MIZU	02.2	05.4	3#	2	100%	9.8	Fl	6.2	Fl	4.2	Fl	6.3	Fl	9.81	5.2
40477M001	MKEA	96.7	05.4	8	3	67%	2.3	Fl	1.2	Fl	1.9	Fl	1.5	Fl	1.52	1.7
40497M004	MONP	96.8	05.4	8	0	78%	2.8	Fl	1.4	Fl	2.6	Fl	1.6	Fl	1.52	2.1
40138M001	NANO	98.2	05.4	7	41#	84%	1.1	Wh	.6	Wh	1.0	Wh	.7	Wh	.56	.6
14302M001	NICO	97.7	05.3	7	8	78%	2.4	Wh	.9	Fl	.9	Wh	2.2	Wh	1.51	1.3
32809M002	NKLG	00.3	05.4	5	4	88%	4.5	Fl	.8	Fl	1.5	Fl	4.5	Fl	4.13	2.4
40465M001	NLIB	95.7	05.4	9	4	62%	2.4	Fl	1.0	Fl	1.9	Fl	2.5	Fl	1.99	1.7
12717M004	NOT1	00.8	05.4	4	0	92%	2.9	Fl	.6	Fl	.9	Fl	2.7	Fl	2.59	1.8
12717M003	NOTO	96.1	00.7	4	14	93%	4.6	Fl	1.2	Fl	1.3	Wh	4.4	Fl	1.82	2.5
92701M003	NOUM	98.2	05.4	7	2	55%	2.5	Fl	1.2	Fl	1.7	Fl	2.9	Fl	1.90	2.1
13234M003	NPLD	01.1	05.4	4	20	91%	2.7	Fl	.8	Fl	2.2	Fl	1.5	Fl	2.12	1.8
40114M001	NRC1	96.1	05.4	9	2	89%	2.3	Fl	.7	Wh	1.2	Fl	2.3	Fl	1.79	1.5
12364M001	NRIL	00.8	05.4	4	2	46%	1.5	Fl	1.2	Wh	1.0	Fl	.8	Fl	1.69	1.2
12312M001	NSSP	98.3	05.4	7	54#	66%	3.2	Wh	1.3	Wh	.8	Wh	3.5	Wh	.59	1.4
22601M001	NTUS	97.7	05.4	7	19	78%	3.9	Wh	1.6	Wh	2.4	Fl	3.8	Fl	2.20	2.1
12319M001	NVSK	01.2	05.4	4	9	96%	6.3	Fl	.9	Fl	.7	Fl	6.3	Fl	2.98	3.2

10317M003	NYA1	98.3	05.4	7	2	97%	2.7	Fl	.8	Fl	.6	Wh	2.7	Fl	2.56	1.9
10317M001	NYAL	95.9	05.4	9	8	78%	2.5	Fl	1.2	Fl	1.3	Fl	2.6	Fl	1.46	1.8
14208M003	OBE2	01.6	05.4	3#	1	98%	2.8	Fl	1.0	Wh	.2	Fl	2.6	Fl	2.17	2.0
14208M001	OBER	96.5	01.4	4	1	97%	1.5	Fl	.1	Fl	.5	Fl	1.4	Wh	1.04	1.4
66008M001	OHIG	96.1	02.1	6	37#	93%	6.6	Wh	1.0	Wh	1.6	Wh	6.5	Wh	2.51	2.9
66008M005	OHI2	02.1	05.4	3#	8	99%	2.7	Wh	1.7	Fl	1.9	Fl	.8	Wh	2.86	1.4
10402M004	ONSA	95.9	05.4	9	4	90%	2.3	Fl	.7	Fl	.9	Fl	2.3	Fl	2.97	1.7
12750S001	PADO	01.9	05.4	3#	7	93%	3.3	Fl	.9	Fl	1.5	Fl	2.9	Fl	1.48	1.9
11206M006	PENC	97.7	05.4	7	12#	76%	3.3	Wh	1.1	Fl	.9	Fl	3.3	Fl	1.56	1.8
50133M001	PERT	96.1	05.4	9	8	55%	1.4	Fl	1.0	Fl	1.4	Fl	1.7	Fl	1.20	1.5
12355M002	PETP	98.8	05.4	6	1	72%	1.1	Fl	.8	Fl	.4	Wh	1.1	Fl	1.08	1.0
40456M001	PIE1	96.1	05.4	9	0	59%	2.1	Fl	.7	Fl	1.7	Fl	2.0	Fl	1.58	1.9
22003M001	PIMO	99.3	05.2	5	10	93%	6.9	Fl	2.2	Wh	3.7	Fl	6.2	Fl	2.82	3.4
12348M001	POL2	96.1	05.4	9	14	85%	2.4	Fl	1.0	Wh	1.1	Wh	2.5	Fl	1.72	1.5

Table 1 (Cont.). Stability estimators for 189 IGS stations, 1995.0-2005.4

DOMES No	Stn	Start	End	#	%Ms	PCT1 Expl.	ASdv mm	Ns	1-yr All_StDv, Noise East mm		North mm		Up mm		Scal fact	Stb ind
14106M003	POTS	95.7	05.4	9	6	84%	2.0	Fl	.7	Fl	.7	Fl	2.0	Fl	2.18	1.4
40124M001	PRDS	97.7	05.4	7	13#	94%	2.7	Fl	.9	Fl	1.9	Fl	1.8	Fl	1.73	1.8
14234M001	PTBB	00.4	05.4	4	32#	58%	1.5	Wh	1.4	Wh	.3	Wh	1.8	Wh	.61	.9
40433M004	QUIN	96.1	05.4	9	19	84%	5.1	Fl	2.0	Fl	1.7	Wh	5.1	Fl	1.47	2.6
35001M002	RABT	01.1	05.4	4	3	77%	.9	Fl	1.0	Fl	.1	Fl	.7	Fl	.89	1.0
20703S001	RAMO	98.5	05.4	6	12	91%	5.5	Fl	4.5	Fl	3.6	Fl	2.0	Wh	4.12	2.9
40149M001	RESO	01.9	05.4	3#	13	69%	1.8	Fl	1.3	Fl	1.5	Wh	1.0	Fl	1.36	1.5
10202M001	REYK	96.1	05.4	9	2	59%	3.6	Fl	1.7	Fl	2.1	Fl	3.5	Fl	2.98	2.5
41507M004	RIOG	97.7	05.4	7	1	88%	2.4	Fl	1.0	Fl	.9	Fl	2.3	Fl	1.93	1.5
41705M003	SANT	96.0	05.4	9	3	90%	4.7	Fl	1.9	Fl	1.7	Fl	4.5	Fl	3.60	2.7
40133M002	SCH2	97.5	05.4	7	3	79%	2.2	Fl	.8	Fl	1.8	Fl	2.3	Fl	2.16	1.9
12352M001	SELE	97.6	05.4	7	3	86%	3.1	Fl	.9	Fl	1.4	Fl	2.9	Fl	2.35	2.1
39801M001	SEY1	96.1	05.2	9	68#	91%	7.8	Wh	3.5	Wh	2.0	Wh	7.0	Wh	.87	3.0
	SFEL	01.7	05.4	3#	4	98%	3.2	Wh	1.4	Fl	1.1	Wh	2.7	Fl	2.54	1.7
13402M004	SFER	98.2	05.4	7	9	86%	3.2	Wh	2.7	Fl	2.0	Fl	1.9	Fl	1.95	1.7
21605M002	SHAO	96.1	05.4	9	31#	76%	1.3	Wh	.6	Wh	.8	Wh	1.4	Wh	.69	.8
40460M004	SIO3	97.0	05.4	8	64#	74%	5.6	Wh	1.7	Wh	4.4	Wh	5.4	Wh	.38	2.4
10090M001	SJDV	98.6	02.5	3#	22#	77%	2.2	Fl	.3	Wh	.8	Wh	2.0	Fl	.69	1.3
11101M002	SOFI	97.6	05.4	7	60#	65%	3.3	Wh	2.4	Wh	.7	Wh	3.1	Wh	.27	1.4
49907S001	SOL1	98.2	05.4	7	43#	85%	5.2	Wh	1.3	Wh	1.2	Wh	5.1	Wh	.45	2.0
40101M001	STJO	96.1	05.4	9	1	70%	2.4	Fl	.8	Fl	1.4	Fl	2.4	Fl	2.62	1.7
30314M002	SUTH	98.3	05.3	7	8	85%	5.7	Fl	1.5	Wh	2.0	Wh	5.7	Fl	4.63	2.9
30314M004	SUTM	02.2	05.4	3#	4	75%	.1	Fl	.3	Wh	.8	Fl	.1	Fl	.37	.8
23903M001	SUWN	98.4	05.4	7	7	85%	2.5	Fl	.8	Wh	1.1	Fl	2.5	Fl	1.53	1.9
66006S002	SYOG	99.4	05.4	5	17#	68%	2.8	Wh	1.2	Fl	1.8	Fl	2.1	Wh	1.81	1.3
92201M009	THTI	98.5	05.4	6	11	92%	3.1	Wh	.5	Wh	1.0	Wh	3.1	Wh	2.57	1.5
43001M001	THU1	96.0	03.0	7	12	91%	4.0	Wh	1.2	Wh	1.1	Wh	3.9	Wh	2.08	1.8
50103M108	TIDB	96.1	05.4	9	3	69%	2.4	Fl	2.5	Fl	.6	Fl	2.4	Fl	2.20	2.1
12360M001	TIXI	98.8	05.4	6	1	89%	3.4	Fl	.6	Fl	1.4	Wh	3.4	Fl	4.02	2.0
10003M009	TLSE	01.2	05.4	4	3	75%	.8	Fl	.7	Fl	.6	Fl	.6	Fl	.51	1.0
10003M004	TOUL	97.5	01.0	3#	15	76%	1.1	Fl	.4	Wh	.6	Fl	1.0	Fl	.57	.9
50140M001	TOW2	98.5	05.4	6	2	74%	1.5	Fl	.8	Fl	.5	Fl	1.4	Fl	1.38	1.2
20808M001	TRAB	00.2	05.4	5	17	61%	2.8	Wh	1.9	Wh	1.2	Wh	2.1	Wh	1.24	1.2
10302M006	TRO1	98.3	05.4	7	3	78%	2.1	Fl	1.9	Fl	1.5	Fl	2.5	Fl	2.30	1.9
10302M003	TROM	96.1	05.4	9	18#	79%	3.4	Fl	2.2	Fl	1.3	Wh	2.9	Fl	1.93	2.0
21730S005	TSKB	96.0	05.4	9	3	83%	2.9	Fl	1.6	Fl	1.5	Fl	2.4	Fl	2.57	1.9
23603S002	TWTF	01.9	05.4	3#	0	96%	4.2	Fl	1.6	Wh	.4	Fl	3.9	Fl	4.17	2.5
24201M001	ULAB	01.6	05.4	3#	14	86%	1.7	Wh	1.4	Wh	.2	Wh	.9	Wh	1.41	.8
41514M001	UNSA	00.3	05.4	5	11	77%	1.9	Wh	.8	Wh	2.0	Fl	1.8	Wh	1.20	1.2
12750M002	UPAD	96.1	01.9	5	6	82%	.8	Wh	.7	Fl	.6	Wh	.5	Fl	.32	.7
49895S001	UPO1	97.2	05.4	8	62#	66%	2.7	Wh	1.3	Wh	2.5	Wh	2.1	Wh	.64	1.2
21612M001	URUM	98.3	05.4	7	14	95%	6.0	Fl	.8	Fl	.9	Wh	5.9	Fl	4.52	3.0

49908S001	USNA	98.2	05.4	7	41#	80%	5.2 Wh	2.9 Wh	1.3 Wh	4.8 Wh	2.09	2.5
40451S003	USNO	97.5	05.4	7	1	64%	2.0 Fl	.7 Fl	1.7 Fl	1.8 Fl	2.10	1.5
21729S007	USUD	96.0	05.3	9	3	63%	3.3 Fl	.9 Fl	2.0 Fl	4.1 Fl	2.79	2.3
66009M001	VESL	98.7	05.4	6	33#	93%	3.6 Wh	1.6 Wh	.7 Wh	3.7 Wh	.44	1.7
13406M001	VILL	96.1	05.4	9	4	54%	2.6 Fl	1.3 Fl	1.3 Fl	2.5 Fl	1.91	1.7
	VOLT	01.7	05.4	3#	4	97%	1.9 Wh	.7 Fl	.8 Wh	1.5 Fl	1.40	1.1
40440S020	WES2	95.9	05.4	9	4	63%	4.5 Fl	3.7 Fl	3.2 Fl	3.5 Fl	4.06	3.1
40136M001	WHIT	96.5	05.4	8	3	87%	4.2 Fl	1.6 Fl	.6 Fl	4.4 Fl	4.29	2.5
40134M001	WILL	96.1	05.4	9	7	73%	1.6 Fl	.6 Fl	1.5 Fl	1.2 Wh	.99	1.2
13506M005	WSRT	97.5	05.4	7	2	88%	3.2 Fl	.3 Fl	.7 Fl	3.2 Fl	4.38	2.0
14201M010	WTZR	96.1	05.4	9	3	79%	2.3 Fl	.9 Fl	.6 Fl	2.3 Fl	3.29	1.7
21602M001	WUHN	96.6	05.4	8	1	98%	11.2 Fl	1.6 Fl	1.0 Fl	11.2 Fl	9.43	5.6
12353M002	YAKT	01.2	05.4	4	6	90%	3.9 Fl	1.9 Wh	.9 Wh	3.4 Fl	4.12	2.1
	YAKA	98.2	01.5	3#	8	90%	1.0 Fl	.9 Fl	.4 Fl	.0 Fl	.79	1.2
50107M004	YAR1	96.1	05.4	9	4	98%	5.5 Fl	1.7 Fl	1.1 Wh	5.2 Fl	5.67	3.2
13420M001	YEBE	00.8	05.4	4	36	99%	2.1 Wh	.1 Wh	.2 Wh	2.1 Wh	.88	1.0
40127M003	YELL	96.1	05.4	9	3	56%	1.9 Fl	1.3 Fl	1.4 Fl	1.3 Fl	2.20	1.5
12329M003	YSSK	99.6	05.4	5	1	92%	2.7 Fl	.9 Fl	2.5 Fl	1.1 Wh	3.72	2.1
12351M001	ZECK	97.8	05.4	7	12	74%	3.2 Fl	1.1 Fl	1.1 Fl	3.2 Fl	2.21	1.9
14001M004	ZIMM	96.1	05.4	9	15	96%	3.5 Wh	1.2 Wh	.6 Wh	3.5 Wh	.46	1.8
12330M001	ZWEN	95.7	04.9	9	25#	81%	3.5 Wh	1.4 Wh	1.8 Wh	3.5 Wh	2.64	1.9

Table 2. Least stable IGS stations. The first and second stability indices refer to the data starting in 1995 and 1999 respectively, with known discontinuities and other defects corrected. The third one refers to an earlier version of the post 1999 data, where the discontinuity corrections were not applied.

DOMES No	Sta	Stability index 1995+	1999+	Discontinuities corrections at		Stab. index uncorrected 1999+
50127M001	COCO	4.5	4.9	2000.46		4.7$
41703M003	EISL	1.3#	1.5	2002.61	2003.10	5.9£
30608M001	GOUG	2.7	2.5			5.5&
10204M002	HOFN	5.5	4.8&	2001.72		5.2&
40150M001	INVK	4.8&*	4.8&*	2003.64		5.1&*
43005M001	KELY	4.9	5.3&	2001.70		4.3&
40424M004	KOKB	4.8	5.9£	2002.73	2004.38	4.4
66001M003	MCM4	2.8	1.8	1999.10		5.2
21702M002	MIZU	5.2*	5.2*	2003.40		3.5*
66009M001	VESL	1.9&#	7.7#			1.7#
21602M001	WUHN	5.6	6.4&	2002.07	2002.84	11.5&

* Data span shorter than 3.5 years

Sparsely observed (more than 30% missing weeks or data gap > 200 days)

Anomalous behaviours: East ($), North (£), or Up (&)

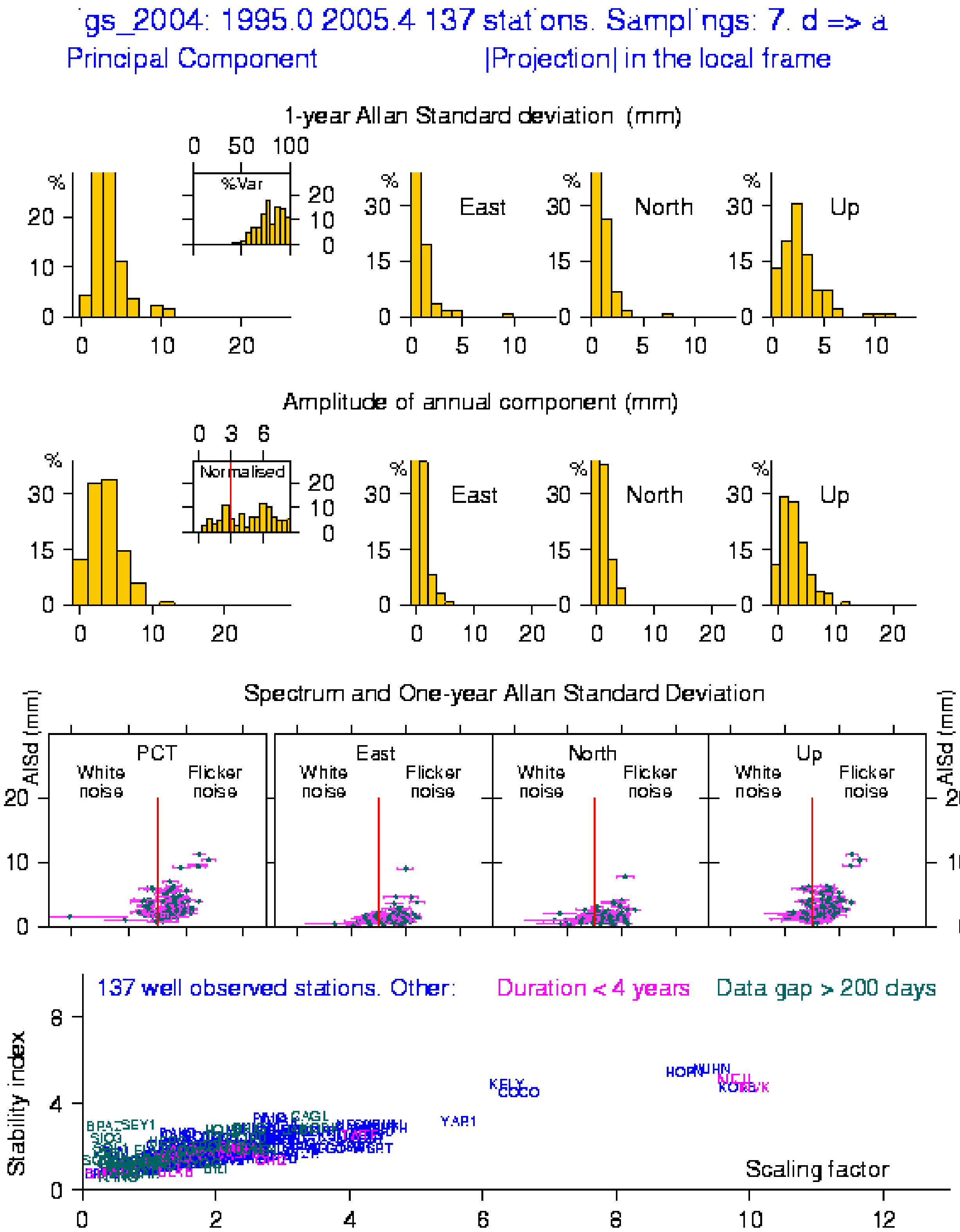

Figure 1. Principal Component analysis in the Time domain of IGS stations non linear motion, spectral diagnoses, evaluation of stability at one-year intervals and scaling factor of the uncertainties.

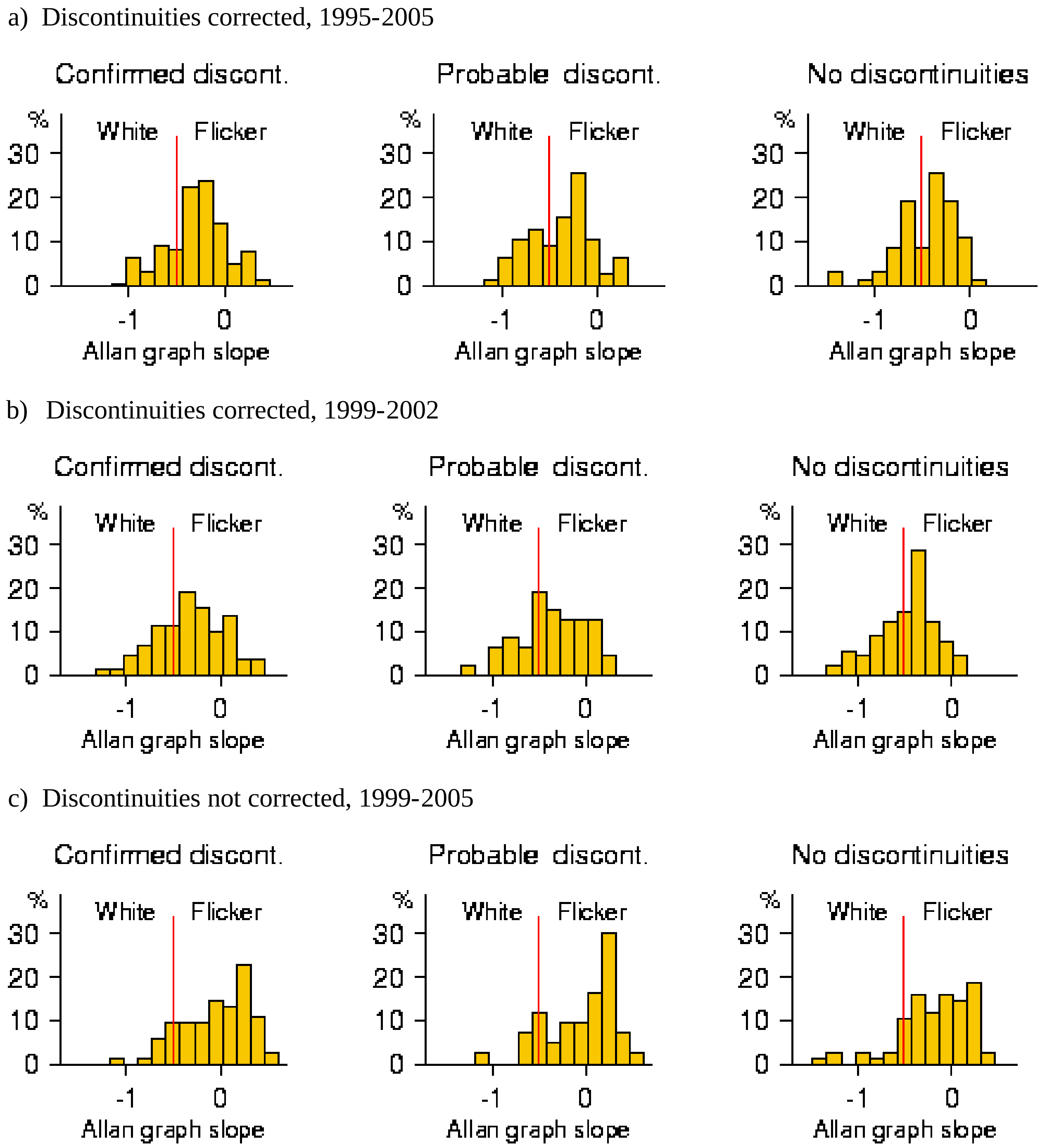

Figure 2. Histograms of the Allan graph slopes of the non linear signal in IGS stations: a) data analysed from 1995.0 on with discontinuities corrected; b), c) series from 1999.0 on with discontinuities corrected and uncorrected, respectively.

4. Summary

The main findings of this analysis of the non linear station motions (residual signal) of 189 IGS stations observed over 1995.0-2005.4 are as follows.

- Annual signatures at the 3-σ level are present in more the half of the stations, mostly in the Up component.
- The residual signal is highly consistent in the time domain, with the first Principal Component in the Time domain (PCT) explaining over 80% of the variance in most cases. The Up direction is the major contributor to the first PCT.
  A large majority of the analysed non linear station motions have a flicker noise spectrum.
- The scaling factors based on the one-year stability cover a wide rage: from 1 through 5, with a few larger values.
- Most stability indices are better than 4. The least stable stations and their stability indices are listed in Table 2. Note that correcting discontinuities improves in general the stability index, but not in all cases. The suggested stations suitable for long term consistency referencing are those with no flag (#) and a stability index smaller than 4 or 5 in Table 1.

5. References

- Ferland, R., 2005. Personal communication
- Le Bail, K., 2005. Estimating the noise in space-geodetic positioning. The case of DORIS. JoG (submitted)

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GLONASS Orbit Determination

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Introduction

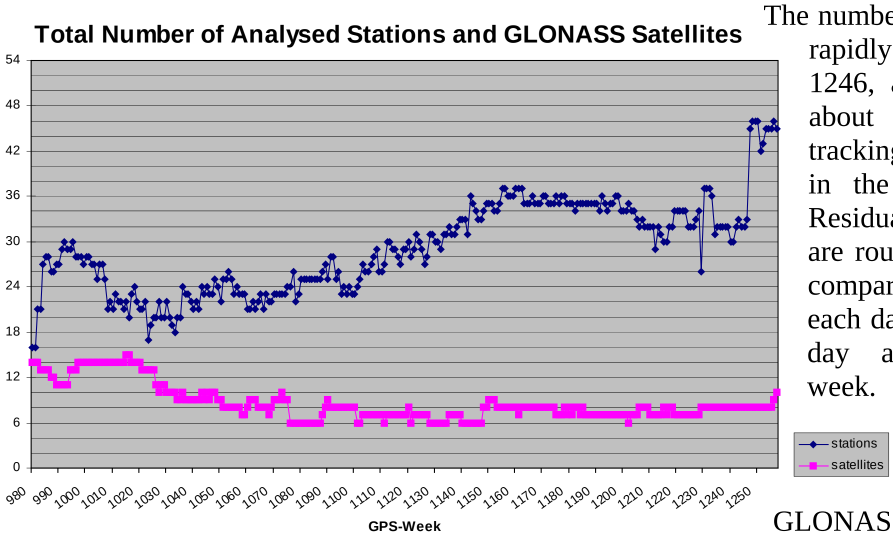
The Federal Agency for Cartography and Geodesy (BKG) analysis combined GPS/GLONASS observations of global tracking stations since the beginning of the International GLONASS Experiment IGEX-98 in October 1998. Weekly analysis reports are submitted by the former IGEX- and nowadays IGLOS- Mail exploder. The following products are publicly available:

- Improved orbits for GLONASS satellites,
- Daily transformation parameters between the GLONASS reference frame (PZ90) and ITRF,
- Receiver-specific estimates of the system time difference between GPS and GLONASS, and
- Station coordinates (SINEX files).

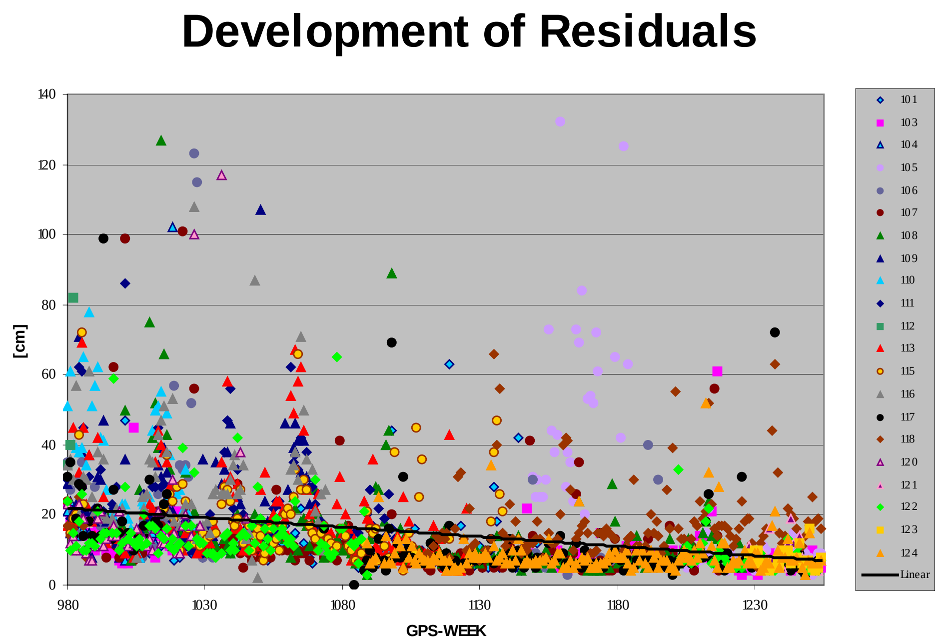
Analysis Procedure

We use the Bernese GPS software for the analysis of combined GPS/GLONASS observations by considering the satellite specific signal frequencies and different realizations of reference frames and system time. There is no attempt to improve the GPS satellite orbits within the analysis procedure, but we use IGS orbits, and solve for GLONASS satellite positions. GPS system time and the ITRF are used as reference for both, GPS and GLONASS. Transformation parameters between PZ90 and ITRF are calculated by Helmert transformations between (1) GLONASS satellite positions resulting from the orbit improvement (in the ITRF) and (2) GLONASS broadcast satellite positions (in PZ90). Thus, the accuracy of the transformation parameters is determined by the broadcast messages, if we assume an accuracy of some dm for the improved GLONASS orbits.

Network and Orbit Residuals



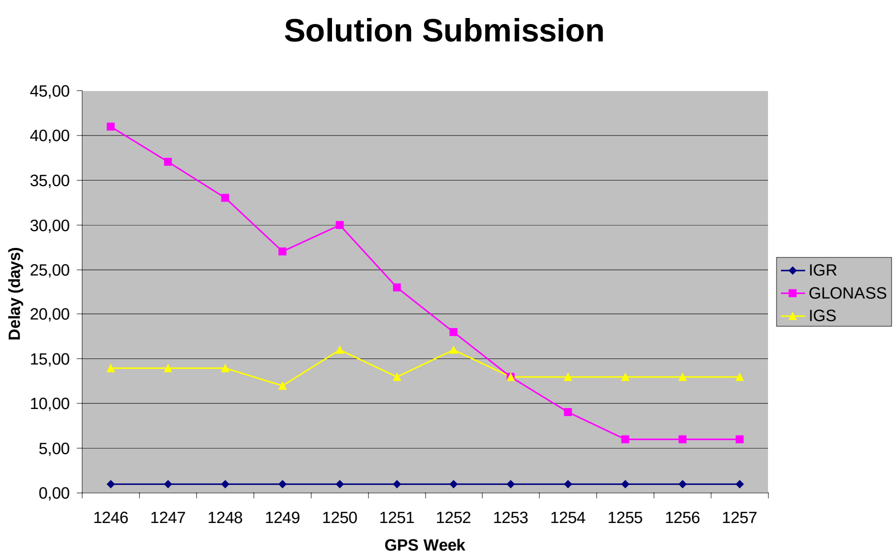
The number of analyzed stations rapidly increased since week 1246, after a careful enquiry about worldwide available tracking data as summarized in the figure to the left. Residuals of orbit positions are routinely derived from a comparison of 3-day arcs for each day of the week to a 7-day arc for the whole week. The development of those orbit residuals since the beginning of the GLONASS processing is given



in the plot on top. The trend line decreases from 22 cm at week 980 to below 10 cm at week 1250. This line was derived from all satellites and is affected by bad performing satellites. The majority of the GLONASS satellites show numbers smaller than the trend.

Orbit Availability

We use IGS-Rapid instead of IGS-Final GPS orbits since week 1246 in order to enable the processing with smaller delay to the end of observation. GLONASS orbits resulting from both approaches had been compared, before that change had been applied to the standard procedure. We found that differences in the resulting orbits could be neglected and concluded that the use of IGS-Rapid orbits for GPS satellites would not degrade our results. BKG is now able to submit the GLONASS orbits within a delay of 2 to 6 days as consequence. With it there might exist the possibility to introduce the BKG GLONASS orbits into the final IGS combination, as illustrated to the left.



CDDIS 2003-2004 Global Data Center Report

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1 Introduction

The Crustal Dynamics Data Information System (CDDIS) has supported the International GNSS Service (IGS) as a global data center since 1992. The CDDIS activities within the IGS during 2003 through 2004 are summarized below; this report also includes any changes or enhancements made to the CDDIS during the past two years. General CDDIS background and system information can be found in the CDDIS data center summary included in the *IGS 1994 Annual Report* (Noll, 1995) as well as the subsequent updates (Noll, 1996; Noll, 1997; Noll, 1998; Noll, 1999; Noll, 2000; Noll, 2001; and Noll, 2004).

2 System Description

The CDDIS archive of IGS data and products are accessible worldwide through anonymous ftp. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is accessible to users 24 hours per day, seven days per week.

In 2003, the CDDIS began a transition from a UNIX server, hostname *cddisa.gsfc.nasa.gov*, to a new Linux-based server, hostname *cddis.gsfc.nasa.gov*; this server became operational in early 2005. The new server is equipped with nearly four Tbytes of RAID disk space and a dedicated DLT tape backup system. All GNSS data and product files are archived in a single file system, accessible through anonymous ftp, and are stored in UNIX compressed format. At present, over 1 Tbytes of on-line disk space are devoted to the storage of GNSS tracking data and products dating since 1992 and the start of the IGS Test Campaign.

During the transition to the new server, the structure of the archive was modified to provide users with a more logical organization of the data and products. This new structure provides consistency between data types (e.g., laser ranging, VLBI, and DORIS). Two main subdirectories are now used, */pub/gps/data* and */pub/gps/products*, with additional mail and report subdirectories. The new directory structure supporting the IGS is described in *http://cddis.gsfc.nasa.gov/ftpgpsstruct.html*.

3 Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to GNSS data from the global IGS network as well as the products derived from the analyses of these data in support of both operational and working group/pilot project activities.

3.1 GNSS Tracking Data

The user community has access to the on-line archive of GNSS data available through the global data center archives of the IGS. Nearly forty operational and regional IGS data centers make data (observation, navigation, and meteorological) available in RINEX format to the CDDIS from selected receivers on a daily (and in many cases hourly and/or sub-hourly) basis. The CDDIS also accesses the archives of the other two IGS global data centers, Scripps Institution of Oceanography (SIO) in La Jolla California and the Institut Géographique National (IGN) in Paris France, to retrieve (or receive) data holdings not routinely transmitted to the CDDIS by an operational or regional data center. A fourth global data center located at the Korea Astronomy and Space Science Institute (KASI) recently began operations in a test mode and routinely supplies data, primarily from stations in Asia and the Pacific, to the CDDIS. Table 1 below summarizes the types of GNSS data archived at the CDDIS.

Table 1a: GNSS Data Type Summary

Data Type	Sample Rate	Data Format	Available On-line
Daily GNSS	30 sec.	RINEX and compact RINEX*	Since 1992
Hourly GNSS	30 sec.	Compact RINEX	Last 5 days
High-rate GNSS	1 sec.	Compact RINEX	Since May 2001
LEO GPS	10 sec.	Compact RINEX	Since 2002

* Note: Amount of non-compact RINEX data available on-line dependent upon available disk space

Table 1b: GNSS Data Archive Summary

Data Type	Avg. No. Sites/Day	Avg. Volume/Day	Total Volume/Year	New Directory Location	Latency of Majority of Data
Daily GNSS	340	425 Mb	150 Gb	*/pub/gps/data/daily*	Within 6 hours
Hourly GNSS	140	125 Mb	N/A	*/pub/gps/data/hourly*	Within 20 minutes
High-rate GNSS	60	700 Mb	250 Gb	*/pub/gps/data/highrate*	Within 90 minutes
LEO GPS	2*	2 Mb	1 Gb	*/pub/gps/data/satellite*	Within 10 days

* Note: Indicates number of LEO satellites

As of June 2003, data from GPS+GLONASS receivers are archived within the GPS directory structure to improve data retrieval for the user community; data from GLONASS-only receivers continue to be archived in the */pub/glonass/data* file system.

The CDDIS archives four major types of GNSS data, all in RINEX format, as described in Table 1a. Daily RINEX data are quality-checked, summarized, and archived to public disk areas in subdirectories by year, day, and file type; the summary and inventory information are also loaded into an on-line database. Over 105K station days from over 340 distinct GNSS receivers were archived at the CDDIS during the each of the past two years; a complete list of these sites can be found in the yearly summary reports at URL *ftp://cddis.gsfc.nasa.gov/pub/reports/gps/*.

Within minutes of receipt, the hourly GNSS files are archived to subdirectories by year, day, and hour. These data are retained on-line for at least five days; the daily files delivered at the end of the UTC day contain all data from these hourly files and thus can be used in lieu of the individual hourly files.

High-rate (typically 1-second sampling) GNSS data are made available to the CDDIS from six principal sources, JPL, NOAA, GFZ, NRCan, Geoscience Australia, and ESA as well as other single-receiver operators (e.g., ASI, GOPE, UNB, NRL, etc.). The RINEX data are archived in files containing fifteen minutes of data and in subdirectories by year, day, file type, and hour.

The CDDIS generates a global broadcast ephemeris file on an hourly basis. This file is derived from the site-specific ephemeris data files for each day/hour. These files are appended to a single file that contains the orbit information for all GNSS satellites for the day up through that hour. This merged ephemeris data file is then copied to the day's subdirectory within the hourly data file system. Several hours after the end of the UTC day, after sufficient station-specific navigation files have been submitted, this concatenation procedure is repeated to create the daily broadcast ephemeris file, using daily site-specific navigation files as input. The daily file is copied to the corresponding subdirectory under the daily file system. Users can thus download this single, daily (or hourly) file to obtain the unique navigation messages instead of multiple broadcast ephemeris files from the individual stations.

The CDDIS continues to archive data from space-borne GPS receiver data from selected missions (e.g., SAC-C and CHAMP) in support of the IGS Pilot Project for Low Earth Orbiting (LEO) Missions. The staff hopes to add data from other satellites such as Jason-1, GRACE, and ICESat.

3.2 IGS Products

The CDDIS routinely archives IGS operational products (daily and sub-daily orbits and clocks, and weekly ERP, and station positions) as well as products generated by IGS working groups and pilot projects. The CDDIS currently provides on-line access through anonymous ftp or the web to all IGS products generated since the start of the IGS Test Campaign in June 1992 in the file system */pub/gps/products*. Products derived from GLONASS data only continued to be archived at the CDDIS in a new directory structure within the file system */pub/glonass/products*.

The CDDIS also continued to archive combined troposphere estimates in directories by GPS week (i.e., */pub/gps/products/WWWW/trop,* where *WWWW* is the GPS week number). Global ionosphere maps of total electron content (TEC) from the IONEX AACs were also archived in subdirectories by day of year (i.e., */pub/gps/products/ionex/YYYY* where *YYYY* is the four-digit year). The CDDIS archived products generated by the individual analysis centers contributing to the IGS LEO Pilot Project (LEO-PP). Thirteen AACs have thus far submitted products for review by the LEO-PP analysis coordinator; these files are archived in subdirectories by AAC within file system */pub/gps/products/leopp*.

3.3 Supporting Information

Daily status files of GNSS data holdings, reflecting timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath continue to be generated by the CDDIS. By accessing these files, the user community can receive a quick look at a day's data availability and quality by viewing a single file. The daily status files are available through the web at URL *ftp://cddis.gsfc.nasa.gov/pub/reports/gps/status*. The daily status files are also archived in the daily GNSS data directories.

Ancillary information to aid in the use of GNSS data and products are also accessible through the CDDIS. Weekly and yearly summaries of IGS tracking data (daily, hourly, and high-rate) archived at the CDDIS are generated on a routine basis. These summaries are accessible through the web at URL *ftp://cddis.gsfc.nasa.gov/pub/reports/gps.* The CDDIS also maintains an archive of and indices to IGS Mail, Report, Station, and other IGS-related messages.

4 System Usage

Figures 1 and 2 summarize the usage of the CDDIS for the retrieval of GNSS data and products for 2004. Figure 1 illustrates the number and volume of GNSS files retrieved by the user community during 2004, categorized by type (daily, hourly, high-rate, satellite, products). Over 52 million files were transferred in 2004, with an average of over four million files per month. Figure 2 illustrates the profile of users accessing the CDDIS IGS archive during 2004. The majority of CDDIS users are from hosts in North America and Europe.

5 Publications

The CDDIS staff attended several conferences during 2003 and presented papers on or conducted demos of their activities within the IGS, including:

- Noll, Carey E and Maurice Dube. "The IGS Global Data Center at the CDDIS – An Update" IGS 2004 Workshop and Symposium, Berne, Switzerland, March 2004.
- Noll, Carey E and Maurice Dube. "Archiving Space Geodesy Data for 20+ Years at the CDDIS" EOS Transactions, American Geophysical Union. December 2004.

Electronic versions of these and other publications can be accessed through the CDDIS on-line documentation page on the web at URL *http://cddis.gsfc.nasa.gov/reports.html*.

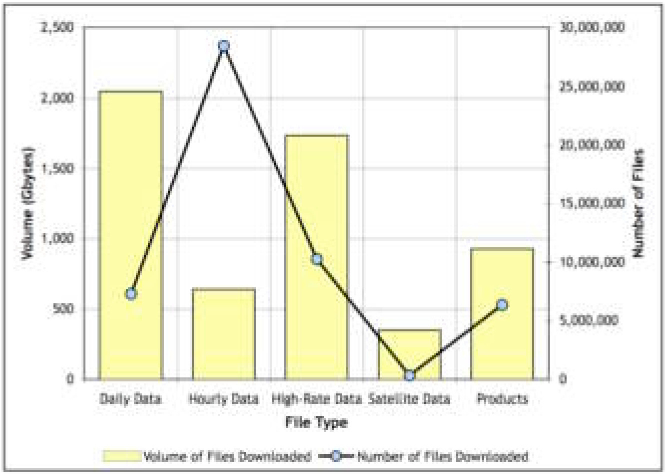

Figure 1: Number and volume of GNSS files transferred from the CDDIS in 2004

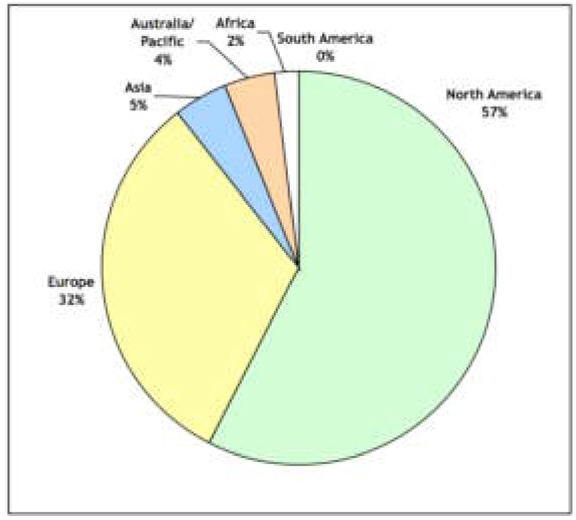

Figure 2: Geographic distribution of IGS users of the CDDIS in 2004

6 Future Plans

The CDDIS server will be augmented with additional RAID disk space in the near future. A DVD writer may also be acquired for long-term archiving activities.

The CDDIS is working with the IGS Real-Time Working Group to develop procedures for receiving real-time GNSS data. Tests are underway to stream the real-time 1-second data to the server from a network of approximately fifteen sites. The data flow and data transfer speeds will be monitored. These tests will help determine the feasibility of a global data center serving as a relay of streaming data to the general user community. The practicality of archiving real-time streams of 1-second data as an alternative to the transmission of the high-rate data in 15-second files will also be tested.

7 Contact Information

To obtain more information about the CDDIS IGS archive of data and products, contact:

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Greenbelt, MD 20771		*http://cddis.nasa.gov*

8 Acknowledgments

The author would once again like to thank the Raytheon Information Technology and Scientific Services (RITSS) contractor staff, Dr. Maurice Dube, Ms. Ruth Kennard, and Ms. Laurie Batchelor. The recognition and success of the CDDIS in many international programs can be directly attributed to the continued dedicated, consistent, professional, and timely support of its staff.

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SOPAC 2003-2004 IGS Data Center Report

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Summary

The Scripps Institution of Oceanography's Orbit and Permanent Array Center (SOPAC) at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP) has served as a Global Data Center and Global Analysis Center for the IGS since its inception in 1994. SOPAC is responsible for the collection, archival, analysis and publication of high-precision continuous GPS data to support the global GPS community. SOPAC's two primary functions, archival and analysis of GPS-related data and data products, serve the interests of the IGS in addition to a number of other complementary SOPAC activities, including: NASA's Southern California Integrated GPS Network (SCIGN) REASoN project, the California Spatial Reference Center, NOAA's Global Systems Division , and UNAVCO, Inc.

Some of the most noteworthy SOPAC activities in 2004, of interest to the IGS, included:

- *Increase in the number of continuous GPS stations archived on a daily basis to over 1400*
- *Increase in the number and geographic distribution of real-time GPS data sources served from SOPAC (see http://sopac.ucsd.edu/projects/realtime)*
- *Increase in the number, scope, and function of interactive user applications, with a strong emphasis on analytical utilities such as GPS timeseries modeling and "any epoch" station positions using precise models.*
- *Increase in total data available to the public to over 7 TB*
- *Addition of several new hosts for GPS data archival and analysis*
- *Integration of spatial database functionality using Oracle Spatial and ESRI ArcSDE to bolster SOPAC web application development and portal services.*

Archive Content and Access

The SOPAC public GPS archive currently contains nearly 7 TB of on-line data. Included in this collection are real-time, 1 Hz GPS data files (24 hour maximum latency), near real-time GPS data files (from minute-level latency), daily GPS RINEX files, related GPS analysis products, GPS site information logs, software, and an assortment of other data files related to the use of GPS data.

The comprehensive age range of files in this collection stretches from 1990 (and sometimes earlier) to one hour ago, all of which are immediately available to the public through anonymous ftp (ftp://garner.ucsd.edu), as well as http (http://garner.ucsd.edu/).

Though the bulk of SOPAC's data collection and archiving activities involves recent data, occasionally older data and/or products are collected or generated. In these instances the files are added to the SOPAC archive as soon as possible, and are subject to the same open data policy as all other data files at SOPAC. This policy includes all data served via ftp or http from the above-mentioned servers, includes no restrictions on data acquisition and is intended to provide public users with the easiest means of collecting data on both a regular and irregular basis. Other than making appropriate acknowledgements[1] for data acquired from SOPAC there are no access restrictions on any data from the SOPAC archive.

GPS Observation Data Files

On a daily basis SOPAC is now archiving RINEX data files for over 1400 continuous GPS stations from around the world (see Figure 1), including the global IGS network (part of SOPAC's role as Global Data Center for the IGS). This number has steadily increased over the past several years, and most likely will continue to increase in the near future. A significant portion of SOPAC's public archive is dedicated to the storage and provision of data files associated with the Southern California Integrated GPS Network (http://www.scign.org), the CORS network operated by the National Geodetic Survey (http://www.ngs.noaa.gov) and the Plate Boundary Observatory (http://pboweb.unavco.org).

RINEX data files are divided into three primary directories on ftp://garner.ucsd.edu, /pub/rinex (observation), /pub/nav (navigation) and /pub/met (meteorological). Raw GPS data files are located under /pub/raw (daily and sub-daily sessions), as well as /pub/highrate/cache/raw (realtime raw data). For a complete list of data and data products available from the SOPAC public archive see http://garner.ucsd.edu/.

[1]Wherever applicable SOPAC strongly suggests acknowledging the source of data or products acquired from SOPAC. In particular, data associated with the Southern California Integrated GPS Network (SCIGN), with UNAVCO, or the IGS, shall require acknowledgement of the variety listed at http://sopac.ucsd.edu/dataArchive/dataPolicies.html.

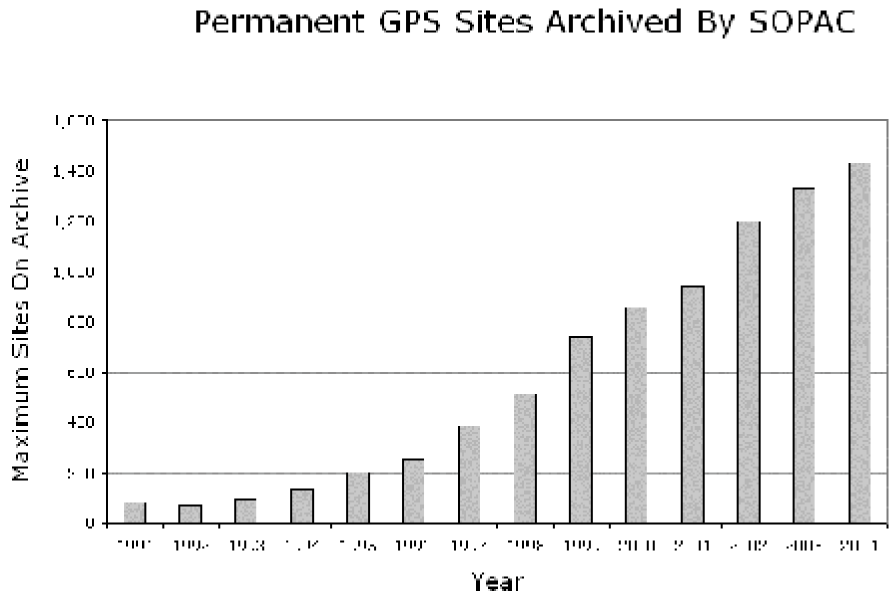

Figure 1. In 2004 the number of continuous GPS sites for which SOPAC archived data increased to over 1400, and will continue to grow rapidly as new stations for Earthscope's Plate Boundary Observatory (PBO) are installed.

GPS Analysis Products

In addition to RINEX and raw GPS data files, GPS products from all IGS analysis centers, including SOPAC (SIO), are available from SOPAC's public archive. These include combined, rapid and predicted orbits, Earth Orientation Parameters, tropospheric estimates, and SINEX solutions. Data required for the GAMIT/GLOBK processing software are also available online.

Weekly products have a latency of 4 days. SIO's predicted and rapid orbits are available within 18 hours from the end of the previous observation day. The IGS combined, rapid and predicted orbits are available within 22 hours from the end of the previous day.

Raw site time series generated from SOPAC's daily and weekly GAMIT/GLOBK processing are archived. Modeled time series from SOPAC's refined model are also available. Outliers and model site parameters, such as site offsets, are included. All time series products are available for download as tar files.

Please refer to our analysis center report in this volume for more information.

Archive Usage

In 2004 the total number of FTP transfers (from the SOPAC public archive) by both public and private users, locally and from around the world (Figure 2) increased by nearly 50% from the number of transfers in 2003, topping 30 million in all (~ 20 million in 2003). Also increasing from 2003, the total number of unique hostnames/clients accessing the SOPAC archive via ftp topped 14000 (Figure 3). Overall, the vast majority[2] of files transferred to these 14000 client machines were RINEX Observation, Navigation and Meteorological files.

SOPAC's user constituency in 2004 was comprised in large part of U.S. educational institutions (.edu domains) and U.S. government institutions (.gov domains). These two domains, combined, on an annual basis, typically account for 40% of all transfers. Another 40% come from machines without identifiable hostnames (e.g. only IP addresses). The remaining 20% is typically distributed across foreign domains and (.com).

As the number of continuous GPS sites archived by SOPAC continues to increase each year, so does the amount of space needed to serve this data and the need for more efficient archiving procedures. Maintaining its public archive has become one of the most important functions for SOPAC over the years, as the demand for data continues to increase rapidly - in an ever-decreasing timeframe (latency). As such SOPAC has been dedicated to improving all aspects of its archive for the GPS community.

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[2] Nearly 95% of all files transferred from SOPAC to public users are RINEX files. This ratio has not changed significantly in the past 8 years.

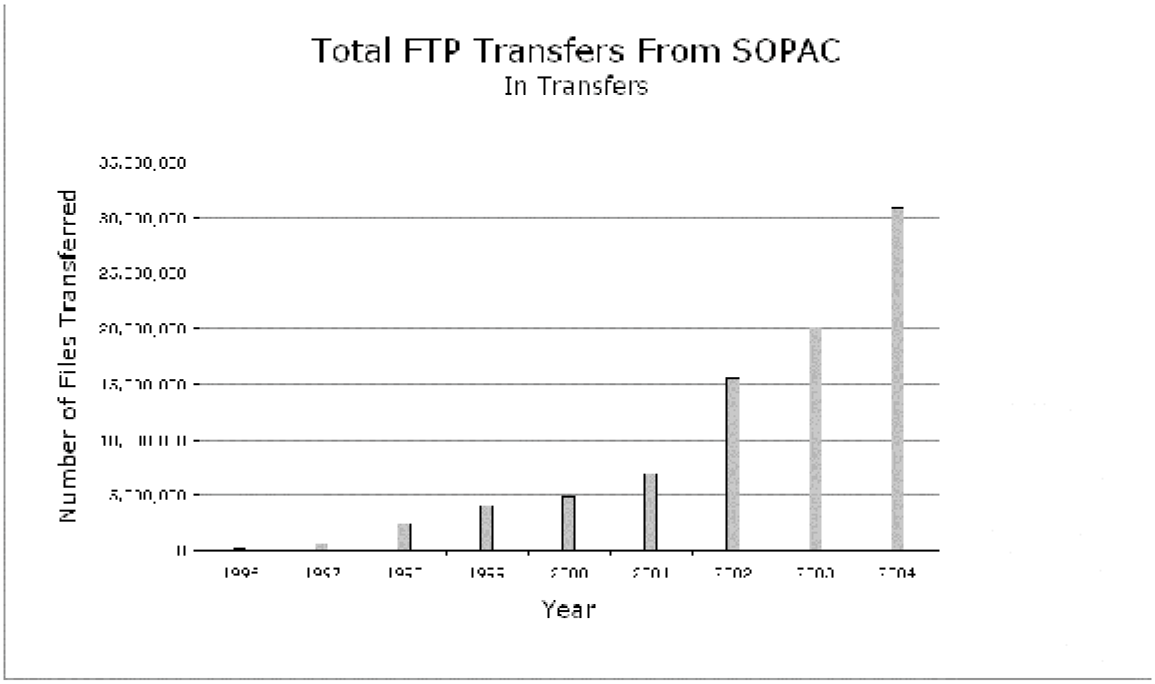

Figure 2. Number of files transferred from SOPAC via ftp://garner.ucsd.edu between 1996 and 2004.

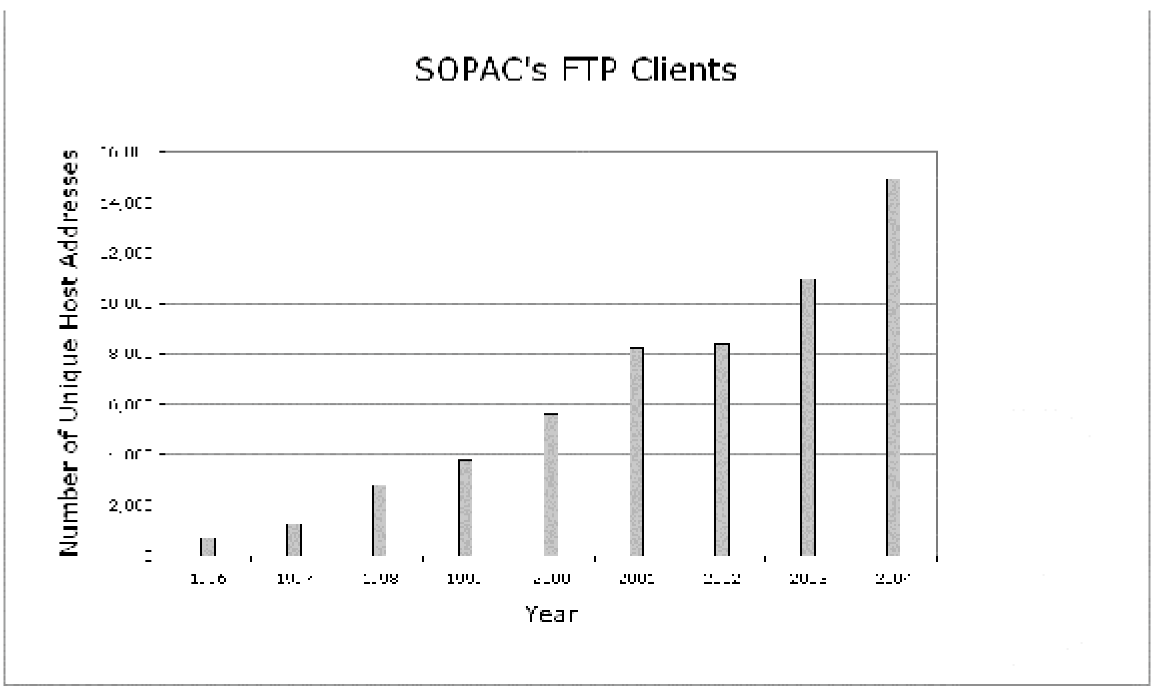

Figure 3. Number of unique clients using ftp to transfer data from SOPAC in the years 1996 through 2004. In the absence of user registration, unique hostnames are used as an indicator of the number of individuals acquiring data from SOPAC.

Systems Architecture

SOPAC owns and maintains over 50 hosts spread across three buildings on the campus of the Scripps Institution of Oceanography. This collection of systems perform a variety of functions, ranging from basic mail servers, to real-time GPS nodes, user workstations, GIS workstations, centralized development library servers, primary public access machines hosting ftp and/or http services, database servers and two dozen GPS data archiving and analysis machines.

SOPAC's public access systems consist of a two Dell PowerEdge servers and a Sun E220R. The Sun server (garner.ucsd.edu) hosts the primary ftp and http interface for the SOPAC public archive. sopac.ucsd.edu, a Dell PowerEdge server hosts all SOPAC web sites. And a second Dell, geopub.ucsd.edu, hosts SOPAC's primary ftp upload service. Together these three hosts play a critical role in providing public access to SOPAC.

From garner.ucsd.edu (via ftp or http) more than 7 TB of data are immediately available to the public 24 hours a day, 7 days a week. Each year approximately 1.5 to 2 terabytes of new data are added to the SOPAC archive. The data available from garner.ucsd.edu is supported through the use of the Network File Systems (NFS) protocol. Filesystems are spread across 4 hosts, and all, except for the AIT tape library SOPAC manages, implement SCSI-based RAID5 configurations.

Archive Management

Over the years, as SOPAC's participation in various projects, particularly, but not limited to, the IGS, has expanded so has the size and complexity of its computational infrastructure and the processes required to construct it, maintain it, populate it and provide access to it. In response, SOPAC has taken steps to automate as many of these tasks as possible, while simultaneously improving other areas of major concern to SOPAC, such as information management and GPS-related scientific research. The most important aspect of this integration and automation has taken the form of a single, robust, Perl-based database application called Archive Data Manager (ADM).

Archive Data Manager (ADM)

Nearly all aspects of managing the SOPAC public archive are fully-automated – driven by a single SOPAC application called Archive Data Manager[3], which derives its configuration, job lists, archive structure (local and remote archives) and other

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[3]ADM, and its supporting collection of libraries, is a custom, system-level Perl application written and maintained at SOPAC. Over the past 3 years ADM has evolved significantly, absorbing numerous tasks once associated with one or more manual functions previously performed by one or more staff members. The flexible nature of ADM, combined with its close relationship with SOPAC's production database, has allowed staff members to direct a greater amount of their time to the analysis of GPS-related information and data files, and the modeling of GPS-related information for wider, community-based initiatives – especially those involving XML.

functioning needs from a relational database schema in an Oracle 9i database server. ADM handles nearly all facets of SOPAC's public archive management and incorporates a number of automated features including 1-second latency GSAC publication of RINEX files and mirroring of RINEX content from the CDDIS and IGN global data centers.

ADM continuously probes and collects data files from more than 40 different local, regional, sub-regional and global GPS archives from around the world. Utmost attention is paid to the efficiency, intelligence and notification capabilities of ADM by SOPAC staff members, especially in relation to the topics of file collection latency, archive availability (up-time), file recollection, IGS data center mirroring, RINEX file quality-checking, GSAC integration, IGS site information log parsing, raw GPS file translation (using teqc) and near real-time RINEX archival.

As the installation of continuous GPS sites around the world continues to increase, and the frequency with which those sites record GPS observations, so does SOPAC's attention to issues related to managing the collection, archival and provision of these datasets in a professional and highly available manner. In response, SOPAC has made several important preparations for the rapid increase in both the number of data files to be collected as well as the total amount of physical space required to store (and serve) these datasets.

Collection-
Collection of data files by ADM occurs in parallel, across numerous SOPAC hosts. Individual processes are launched by Unix cron table entries and communicate through a common relational database server. Since 2001 (when ADM was originally written) a number of improvements have been made with regard to making SOPAC's overall archiving operations more stable, less prone to problems with a particular host, network filesystem, or remote archive and intelligent enough to recognize patterns related to particular files (e.g., quality), local hosts, or remote servers. These enhancements include load balancing, NFS traffic reduction, mirrored data files in two locations and centralized configuration maintained through database-driven user interfaces.

Storage-
Storage components used by ADM are distributed across multiple servers with varying amounts of space, RAM, network bandwidth, up-time expectations, redundancy and file retrieval response times. Typically ADM stores a copy of each file it collects, in a “staging” pool (usually an inexpensive Firewire drive to be shelved when full, and cleaned to tape at a later time), in the primary archive location, and in a secondary archive location (to have two copies online at all times). Depending on the type of data file, and its association with a given project, different assignments are made to different physical storage components. Typically, older, infrequently accessed data, are stored in two separate locations (both online) on inexpensive Firewire drives. More recently, frequently accessed data files are temporarily housed on more expensive RAID disk arrays covered by on-site maintenance contracts. Yet another important storage component utilized and managed by SOPAC, for department use as well, is a 36TB AIT tape library; this system is used to store large, infrequently accessed data files such as

high-rate sampling GPS raw data from realtime networks.

Administration-
As far as actual staff resources are concerned, administration/oversight of ADM occurs primarily through two different means: a) via 'indicator' emails sent to SOPAC staff by ADM, and b) configuration management by SOPAC staff through web-based applications and direct database queries.

The indicator emails highlight actual, as well as potential, problems encountered or anticipated by ADM and allow multiple staff members to remain informed of the general health of the archive. Important topics addressed by ADM in this manner include: filesystem problems (out of space, hung mount points, etc), server-related problems (archive hosts, upload ftp server, etc), file-related problems (quality-checking, small file size, availability issues, etc) and 'discoveries' (previously unknown GPS site possibly found at another archive).

Email notification by ADM works well in a reactive setting, for irregular events and otherwise unanticipated occurrences. However, the configuration of ADM (e.g. what to do, when, how) is managed primarily through SOPAC's Site Information Manager (SIM) and direct SQL interfaces with SOPAC's production database.

Overall, SOPAC's archive management functions remain a top priority and will continue to be a top priority into the foreseeable future. Nearly every week an improvement or addition of some kind is made to the ADM system.

Information Management

SOPAC has been dedicated to providing the GPS community with useful and timely information describing GPS data, or various components related to the use of GPS data for scientific research, education, government and commercial applications since the early 1990s. At the center of nearly all of SOPAC's information management activities is an Oracle 9i relational database. This database is used to model information critical to the functioning of SOPAC and to the assortment of GPS-related activities it performs. Interfaces to the database are many, and vary with the context and regularity with which particular information set is affected. However, one application in particular has received the most development resources over the past several years – SOPAC's Site Information Manager.

Site Information Manager (SIM)
For information associated with GPS sites (or geodetic monuments) SOPAC's primary management tool is the Site Information Manager[4] (Figure 4), a web-based application that allows users to insert, update or delete information associated with one or more GPS sites they have been granted access rights to by a SOPAC staff member. The interface

[4]The SIM launches and runs in a separate browser window, accessible from http://sopac.ucsd.edu/scripts/SIMpl_launch.cgi.

itself uses the same (or very similar) terminology, value domains (such as equipment model codes) and layout as an IGS Site Information Log. SIM users, among other things, can find or specify the site they wish to view/edit and then make changes (assuming they have the necessary access rights) to any information in the SOPAC database associated with the selected site, and supported in the SIM. This information then propagates directly into a variety of functions at SOPAC, many of which serve the interests of the IGS, including:

- Complete IGS site log generation from the SOPAC database on request (by a SIM user).
- Automated generation and submission of SCIGN site logs (for certain sites) to the IGS.
- Parsing/validation of IGS site logs during ADM archival processes.
- Translation of SCIGN raw GPS data files using UNAVCO's teqc utility.
- Creation of publicly-available SINEX products and GAMIT station.info configuration files for GPS analysis.

Over the past 4 years the SIM has undergone numerous updates, to conform to changes in the IGS site log format and to serve a more extensive pool of application contexts at SOPAC. This important interface has served as an invaluable asset in numerous capacities at SOPAC and continues to evolve as needed

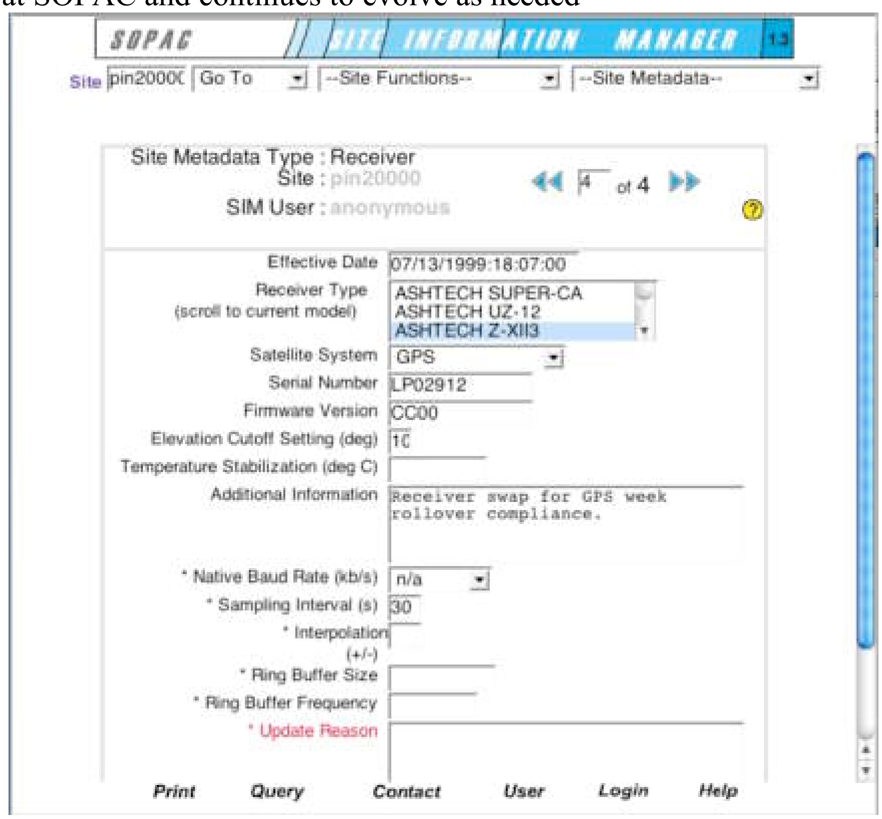

Figure 4. SOPAC's Site Information Manager (SIM) is a web-based database application that allows users to insert, update or delete information content associated with one or more GPS sites.

Automated Information Collection
Much of what ADM (described previously) does, with regard to the IGS, is to automate important tasks such as the parsing of IGS site logs. Whenever a new (or modified) site log appears at one or more ftp archives visited by ADM it is collected and parsed with respect to information present in SOPAC's production database – much of which is managed/overseen by SIM users. Any differences in content are automatically rectified with respect to the database, or shipped to a SOPAC staff member via email for confirmation. This information is then immediately available to most SOPAC applications, including GAMIT's station.info generation, ALL site information-based applications on SOPAC's websites and SOPAC's operational GPS analysis.

The relationship between data file collection (and subsequent provision) and ancillary metadata has received a large amount of SOPAC's development time over the years, as more and more inter-operative and collaborative functions have evolved at SOPAC. Furthermore, the benefits reaped by such development have aided SOPAC significantly in developing a more efficient and effective GPS analysis environment, for local (in-house) and public users alike.

Acknowledgments. We want to thank our IGS colleagues for sharing data, metadata, and metadata with us, and our customers for continuing to use (and stress) our archive. We acknowledge the Southern California Integrated GPS Network and its sponsors, the W.M. Keck Foundation, NASA, NSF, USGS, SCEC, for providing data to SOPAC. Funding also provided by NSF (through UNAVCO), NOAA's Global Systems Division, and NOAA's NGS (through the JIMO program to the California Spatial Reference Center).

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E-mail: mscharber@gpsmail.ucsd.edu

or visit SOPAC's main public website at: http://sopac.ucsd.edu.

KASI Global Data Center Report
(2003 – 2004)

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Introduction

Korea Astronomy and Space Science Institute (KASI) has been contributed IGS since the middle of the 90's as an IGS global station and operational data center. KASI is the national astronomy and space science research institute of Korea established in 1974. KASI opened the history of Korean modern astronomy, and recently, KASI has expended its research area to the space science including space geodesy. Space geodesy research in KASI is currently based on GNSS. In the near future, VLBI and SLR systems are combined to GNSS for the complete space geodesy research in KASI. In 2004, KASI had proposed 4th IGS GDC to contribute more to the international GNSS research communities and to step up the capabilities in GNSS research in KASI. At the end of year 2004, KASI has established GDC system and currently KASI GDC is in the phase of provisional test.

System Description

System Layout

KASI GDC system layout is described in figure 1. KASI GDC consists of two data storage servers, one DB and web server, tape backup library, and four processing servers. The capacity of KASI storage servers is total of 16 TeraBytes: eight TeraBytes for the main storage and another eight TeraBytes for the backup storage. The storage servers are operated on the Linux operating system. The main and backup storages are managed by SCSI and RAID system. DB and Web servers are on the Microsoft Windows 2003 operating system. Processing servers are dedicated to the various GNSS data processing.

Currently database, web service and FTP control programs are on one control server as described in figure 2. This server controls the data transferring and archiving to the storage servers and manages the database. Main and backup storage servers can be switched in the case of a storage failure. KASI runs FTP master program on the control server. FTP master in figure 3 manages FTP scheduling, data archiving, and DB control.

Power Supply and Network

System power is stably provided by the KASI power supply and unexpected power outage can be handled by an emergency power generator and a large capacity UPS system.

KASI GDC service works on a 155Mbps network system. All the incoming and outgoing data, worldwide anonymous FTP service (ftp://gdc.kasi.re.kr), and World Wide Web service (http://gdc.kasi.re.kr) are via the independent network.

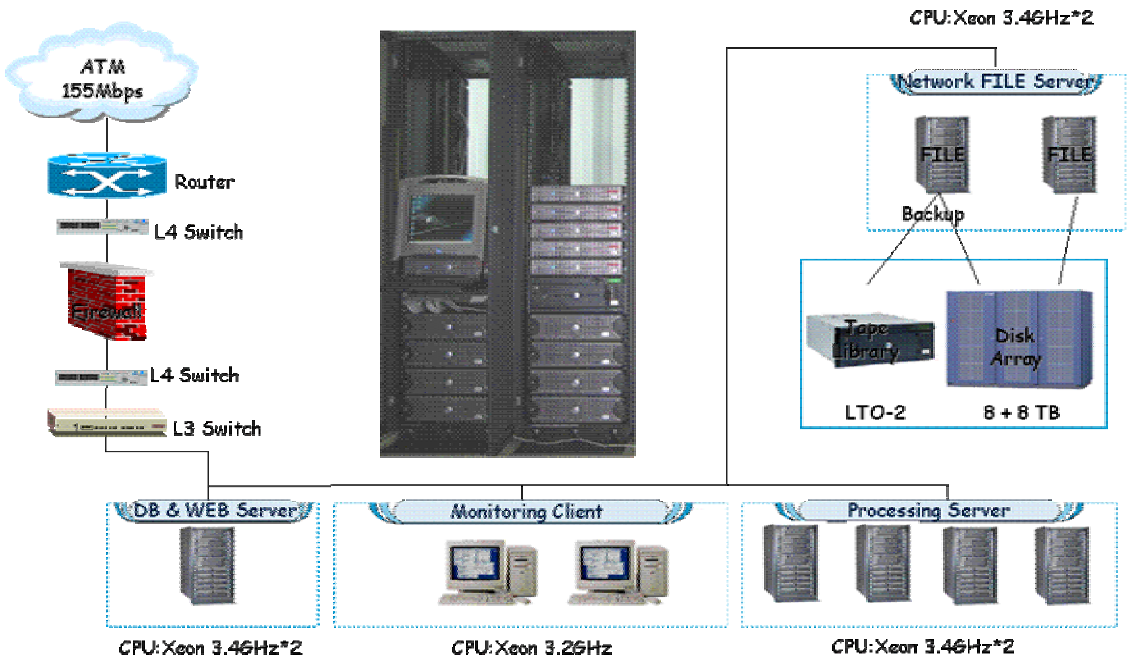

Figure 1. System Layout

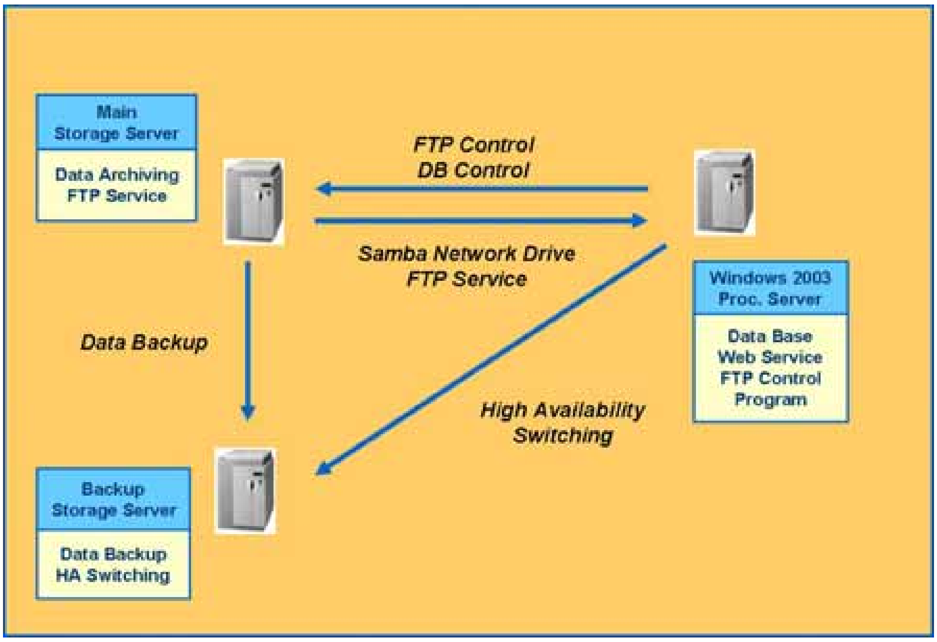

Figure 2. GDC Functional Architecture

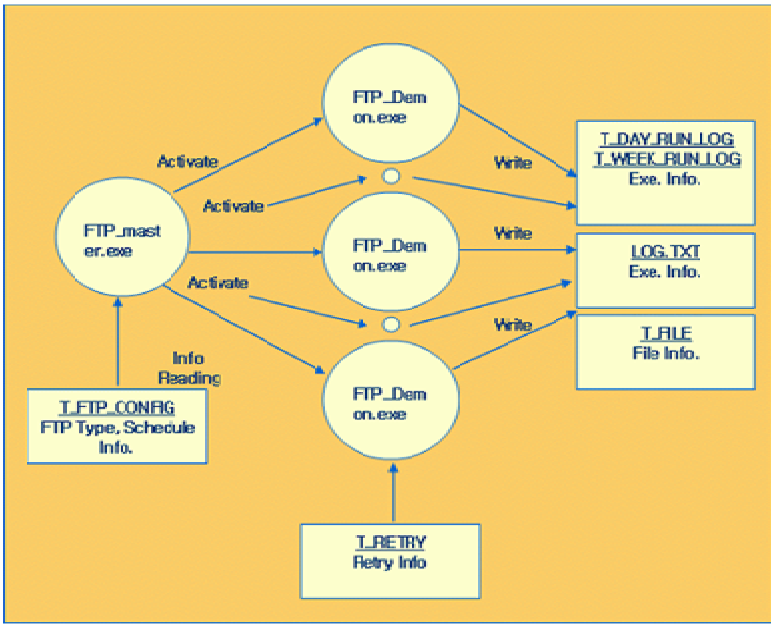

Figure 3. FTP Control Flow

Services

KASI stores all the GNSS data and products from 1994 to present. KASI archives daily and hourly, and high-rate data from more than 350 IGS sites and provides all the archived data to IGS user communities. KASI collects GPS daily, hourly, and high-rate data directly from the regional and operational IGS data center in Asia-Oceania, and transfers the data to the other IGS GDC. Currently KASI transfers the regional data to CDDIS only. IGS product including troposphere and ionosphere data are also archived from IGS ACC, IGS CB and CDDIS. GLONASS data and products, and LEO satellite data are also archived.

KASI operates a web portal service for convenient user interface to provide various GNSS data and related information. The web portal system provides data browsers, data download service, and direct FTP server connection. In figure 4 and 5 shows the main page and data browser page of KASI web portal service, respectively. Statistics for the archived data and transferred data, and web access, are managed by the system database and provided in the web portal system. Some of the fundamental information and useful links are provided as well.

Figure 4. KASI GDC Web Service (http://gdc.kasi.re.kr)

Figure 5. Web Data Browser

Archived Data Status

KASI GDC data archiving folder structure was instructed by IGS data center working group (DCWG). In figure 6, the public folder layout is described and table 1 summaries the KASI data archiving status.

Data flows

KASI keeps two main data flow. One is the data flow of Asia-Oceania regional and operational data center to KASI. This flow of data includes daily, hourly, and high-rate data. Another flow is the data archiving from other GDC for data traffic sharing and redundancy purpose. Currently KASI achieves the data from CDDIS for most of the data, product type and also from IGS ACC for IGS final, rapid, ultra-rapid orbit products.

Public Service Directories

KASI public FTP server is “nfs.kasi.re.kr” and directories for the archived data are summaries in table 2.

Table 1. Data Status Summary

Data type	Availability	Volume/day	Total volume	Note
GPS daily	1994 ~ current	~ 400 MByte	~ 400 GByte	
GPS hourly	~ current	~ 70 MByte	~15 GByte	
GPS high-rate	~ current	~ 500 MByte	~110 GByte	
GPS LEO	2002 ~ current	~ 3 MByte	~ 3 GByte	
IGS orbit product	1994 ~ current	~ 30 MByte	~ 4 GByte	Volume/week
IGS troposphere	1997 ~ current	~ 1 MByte	~ 1 GByte	Volume/week
IGS ionosphere	1998 ~ current	~ 2 MByte	~ 2 GByte	
IGS documents	1992 ~ current	-	~ 300 MByte	

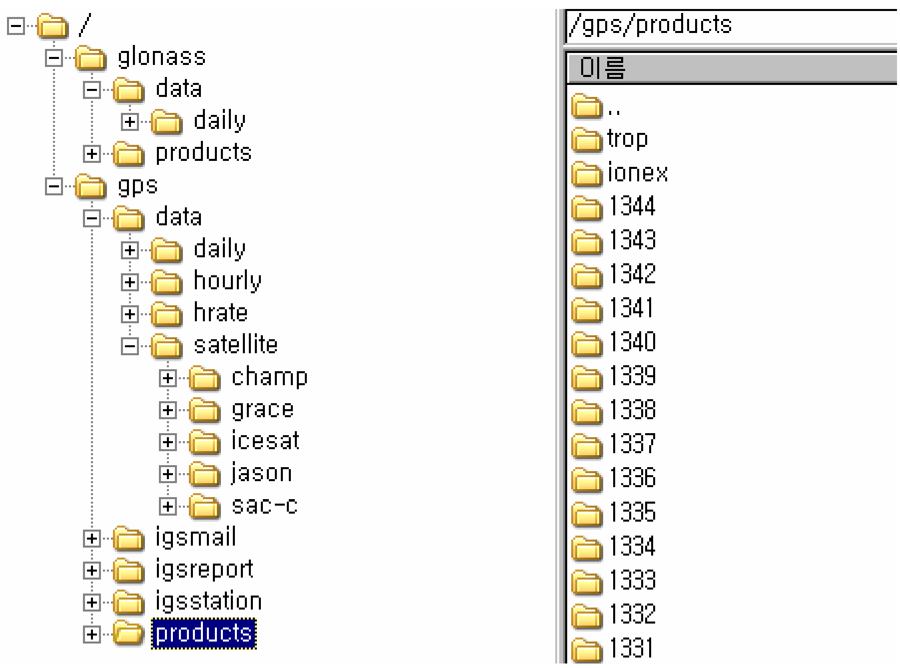

Figure 6. Public Directory Layout

Table 2 Public Service Directories

Data	Directories	Note
GPS daily	/gps/data/daily/yyyy/ddd/yyd /gps/data/daily/yyyy/ddd/yyg /gps/data/daily/yyyy/ddd/yym /gps/data/daily/yyyy/ddd/yyn /gps/data/daily/yyyy/ddd/yyo /gps/data/daily/yyyy/ddd/yys	yyyy: year in 4 digit ddd : day of year in 3 digit yy : year in 2 digit
GPS hourly	/gps/data/hourly/yyyy/ddd/hh	hh : hour in 2 digit(0 ~ 23)
GPS high-rate	/gps/data/hrate/yyyy/ddd/yyd /gps/data/hrate/yyyy/ddd/yym /gps/data/hrate/yyyy/ddd/yyn	
GPS LEO	/gps/data/satellite/xxxx/yyyy/ddd	xxxx : champ grace icesat jason sac-c
IGS orbit product	/gps/products/wwww/igs	wwww: GPS week
IGS troposphere	/gps/products/trop/wwww	
IGS ionosphere	/gps/products/ionex/yyyy/ddd	
IGS documents	/gps/igsmail /gps/igsreport /gps/igsstation	

Future Plan

KASI GDC is schedule to perform provisional test and performance upgrade in year 2005. After the provisional test, KASI is expecting the official launch of GDC in year 2006. During the test period, KASI will organize Asia-Oceania regional and operational data centers for the direct data transfer to KASI.

KASI is planed to upgrade the network reliability by setting up the redundancy network system to avoid possible network outage. KASI also has a plan to regular backup of CDDIS by mirroring. IGS inter-GDC backup policy needs to be discussed in the DCWG. Real time data streaming support and data archiving need to be also considered in the near future.

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Acknowledgement

KASI would like to express appreciation to the IGS colleagues, especially to Carey Noll, Peng Fang, and Edouard Gaulue for all the technical advices and supports on the KASI GDC establishment.

BKG Regional GPS/GLONASS Data Center

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Federal Agency of Cartography and Geodesy, Germany

Introduction

The Federal Agency for Cartography and Geodesy (BKG) operates the Regional IGS Data Center for Europe since the beginning of the IGS Test Campaign in June 21, 1992. GPS tracking data from permanent GPS sites in Europe are obtained from Operational Data Centers (ODC's), Local Data Centers (LDC's), or directly from the stations. Also tracking data from stations outside of Europe are transferred to BKG, if a European institution operates these stations. The received data are uploaded to the Global Data Centers (GDCs), and are also made available to other users. BKG holds the data files from different projects in separate directories in order to handle the project related restrictions, e.g., the project specific user access. A project independent access is additionally realized through a list of all stations and links to the corresponding subdirectories. The operability of the data center is continuously adapted to meet newest requirements.

Data Holding and Transfer

The data center holds currently observation files of 385 stations and distinguishes between 6 projects. Figures 1 to 4 show typical daily data access through the ftp protocol for a period of 16 days. Http access is not counted in this figures. We notice the "multiplying" function of the regional data center from an average data upload amount of about 400 Mbyte per day , whereas the download amount is about 2.5 Gbyte per day.

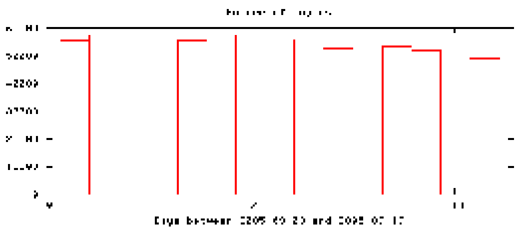

Figure 1: Number of Logins

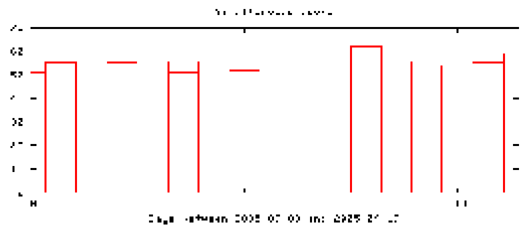

Figure 2: Simultaneous Users

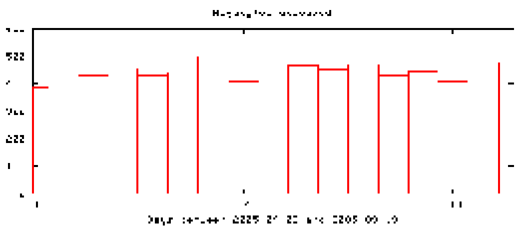

Figure 3: Upload Amount per Day

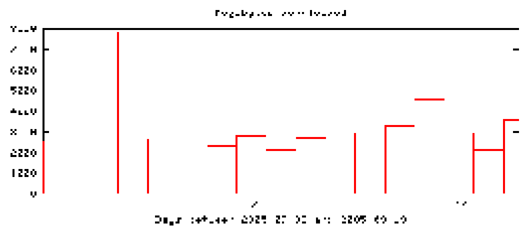

Figure 4: Download Amount per Day

Development of the new Server Concept

BKG decided in 2002 to develop and realize a new server concept for the data center. The objective is to make the access to the data center more comfortable for the users as well as for the administrator. It should be possible to get all information by usage of the http protocol in addition to the existing ftp access. A test server had been installed in 2002 and had demonstrated the functionality of the concept. This test server was further development in 2003 to meet the minimum requirements for the live system and was tested on long term basis in 2004 by operation in parallel to the existing server. An example of the web-application of the new server is given in Figure 5.

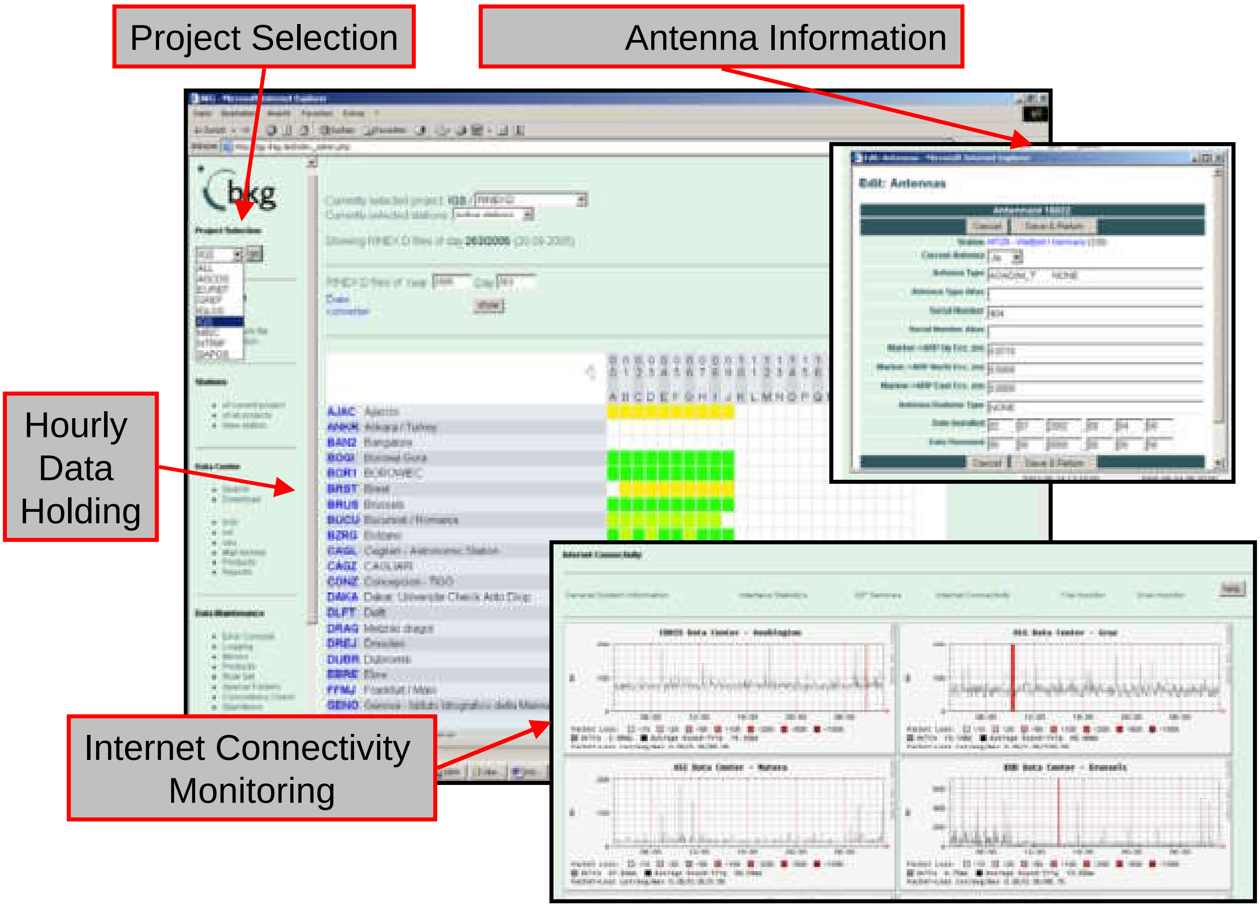

Figure 5: Web-Application of New Server

Outlook

The new data center server will replace the existing one in 2005 as soon as the minimum requirement will be validated. The next steps will be to extend the functionality with useful tools and to improve the design for better user orientation and beauty.

Network Coordination

Angelyn Moore (Jet Propulsion Laboratory, California Institute of Technology))

1 The IGS Tracking Network

During the 2003 calendar year, 24 sites were newly recognized as IGS sites. This set improves the IGS coverage in the Arctic, Pacific, and African regions, and includes a few GPS/GLONASS stations joining the International GLONASS Service Pilot Project (IGLOS-PP). Three stations were decommissioned, bringing the number of IGS stations at the close of 2003 to 363.

2004 saw the addition of 22 more sites, and two decommissionings, bringing the total to 383. These sites include timing laboratories, and several co-locations with SLR, VLBI, and DORIS[1]. The international services of the IAG for these related geodetic techniques[2] have helped to encourage IGS stations at these co-locations. Figure 1 depicts the IGS network at the end of 2004 and Table 1 details the new sites added in 2003 and 2004.

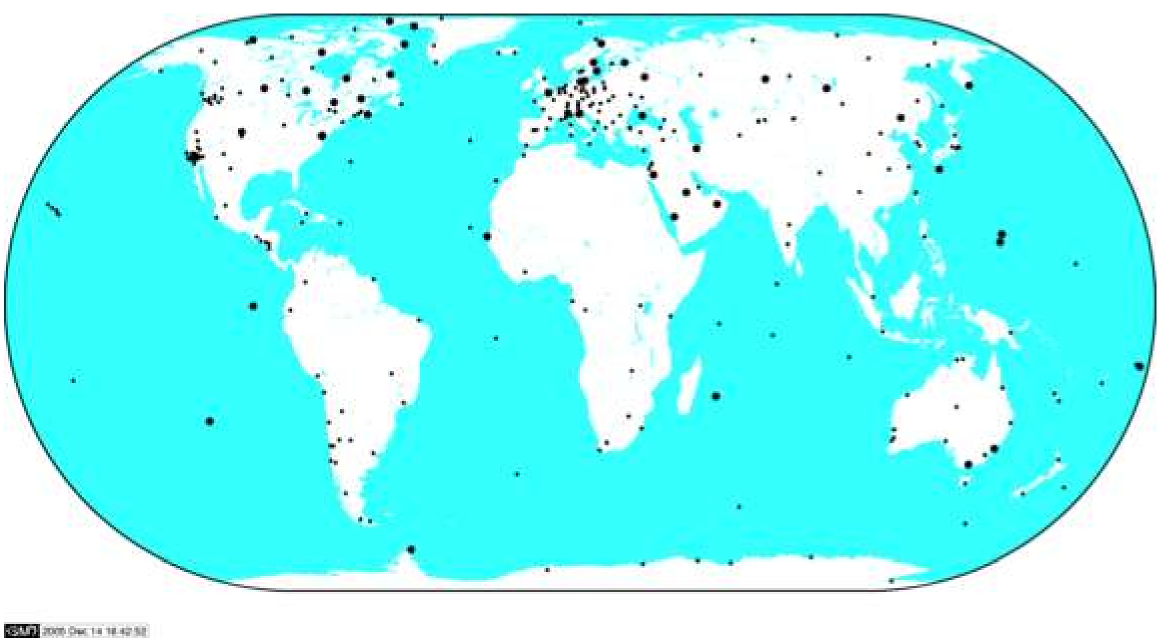

Figure 1: The IGS network at the end of 2004. Large circles are sites added in 2003-2004.

[1]Satellite Laser Ranging, Very Long-Baseline Interferometry, and Doppler Orbitography and Radiopositioning Integrated by Satellite

[2]International Laser Ranging Service (ILRS), International VLBI Service (IVS), and International DORIS Service (IDS)

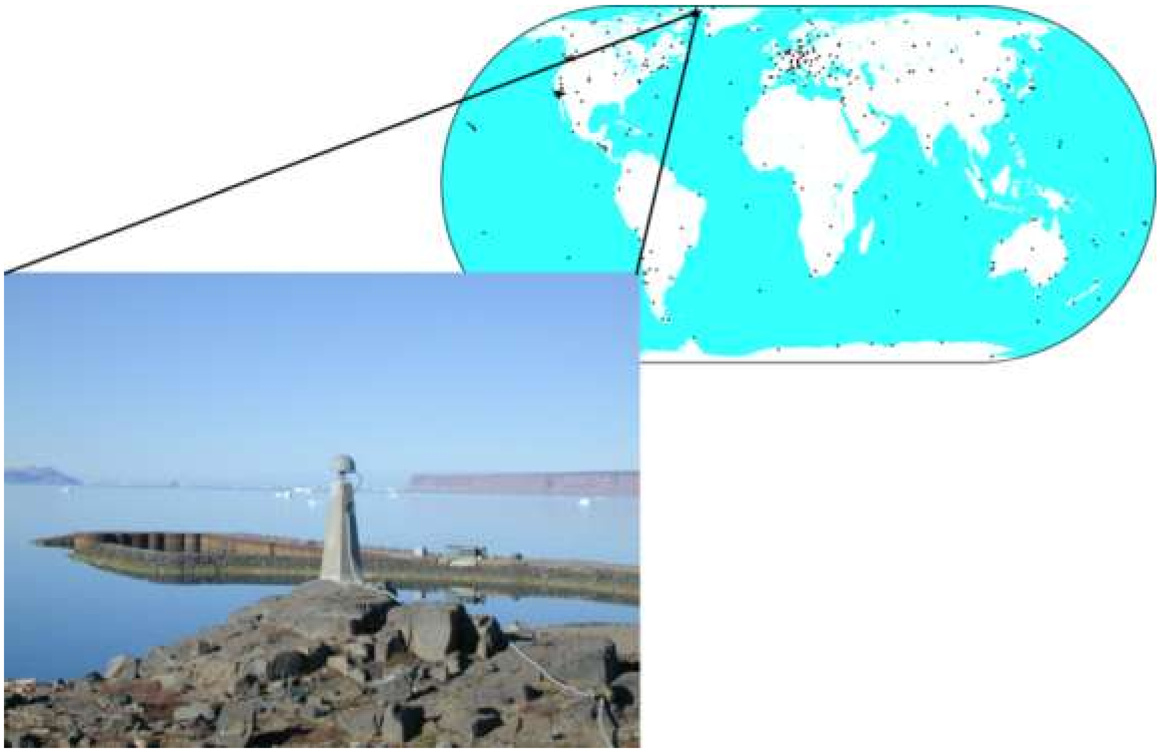

Figure 2: The THU2 IGS station in Thule, Greenland joined the IGS in 2004 (replacing an older, less stably monumented site). Photo courtesy of F.B. Madsen, DNSC.

IGS stations are permanent, continuously-operating, dual-frequency GPS stations operated by many worldwide organizations, including space agencies, mapping agencies, geoscience agencies, and universities. The responsible agencies submit the stations' data to the IGS Data Centers for free and open usage, and supply station configuration information to the IGS Network Coordinator (NC) at the IGS Central Bureau (CB). Typical IGS stations contribute daily data sampled every 30 seconds; growing subsets also contribute 30-second data on an hourly basis or 1-second data four times an hour. 174 stations contributed subdaily data during 2004, as shown in Figure 3.

2 Network coordination milestones

Network coordination activities in 2003-2004 focused on two areas: improvement in feedback of station performance to operators and users, and improvement in documentation of IGS network practices.

Each station has its own automatically-updated page on the IGS CB web, including plots of recent number of observations, cycle slips, and multipath. Trends in these plots can identify equipment problems, unwanted interference at the site, or unreported equipment changes. We upgraded these graphs to include indicators of equipment change (see Figure 4, left) reported to the Central Bureau in the site log, which quickly identifies when the cause of a change in behavior is known.

Moreover, to improve the Central Bureau's efficiency in monitoring the dataset for changes in behavior that require documentation or investigation, we implemented a cumulative sum change-

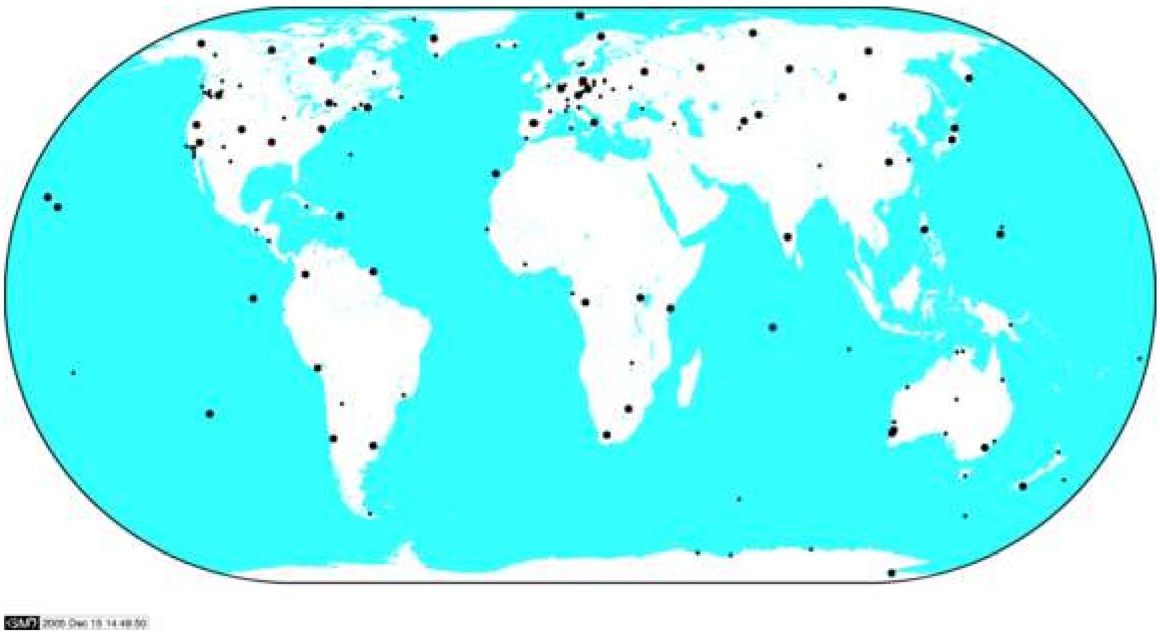

Figure 3: Stations which submitted files on an hourly (small circles) or subhourly (large circles) basis in 2004.

point analysis scheme[3]. This aims to be as accurate as the human eye at detecting a change in behavior in a time series, with higher efficiency. The change points are marked with a question mark on the data quality control plots (see Figure 4, right). and sites with change points are flagged for further examination by the NC.

Residuals from the SINEX combination of station positions and velocities performed by the IGS Reference Frame Coordinator have repeatedly been suggested as a possible station quality indicator, and with the help of the Coordinator, plots of these histories were also offered on the site web pages starting in 2003. These also feature markers of known equipment changes. We also show how that site's most recent residual and standard deviation of the residual over a year compare with all other IGS stations (see Figure 5).

A graph showing recent hourly data latency was also added, to aid in discerning how well hourly sites can contribute to IGS rapid and ultrarapid products. The mean latency and standard deviation are also compared to those of all IGS hourly stations (see Figure 6).

Finally, with the assistance of the IGS Analysis Centers (ACs) and the Analysis Coordinator, we began to collect information on which IGS ACs chose each station for various IGS product types (figure 7). This will be helpful in understanding how each station contributes, and, for example, where an upgrade in station capabilities could result in contribution to a new product class.

3 Station Guidelines

At the 22nd IGS Governing Board meeting, a thorough update of the IGS site guidelines was identified as a pressing priority for a number of reasons. Existing guidelines were in some cases not

[3]Moore, A.W, Jeziorek, P.N., Richardson, E.W., and Neilan, R.E, "Progress in Centralized Monitoring of the International GPS Service Network," *Eos Trans AGU., 85*(17), Jt. Assem. Suppl., Abstract G43C-04

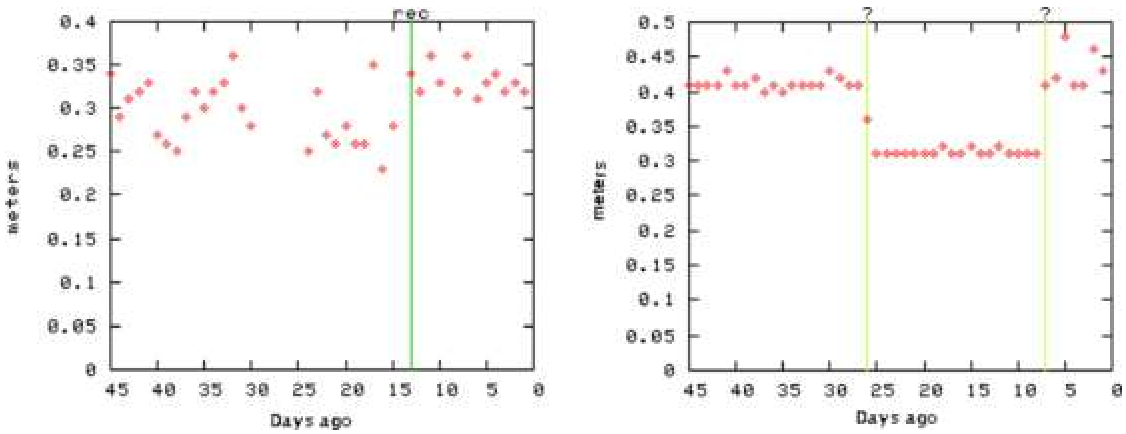

Figure 4: (left) An equipment change at the PIE1 IGS station in Pie Town, USA is marked in a plot of the station's L1 multipath. (right) Change point analysis found a change in the recent L2 multipath, indicating a potential unreported change at the CAGL IGS station in Cagliari, Italy.

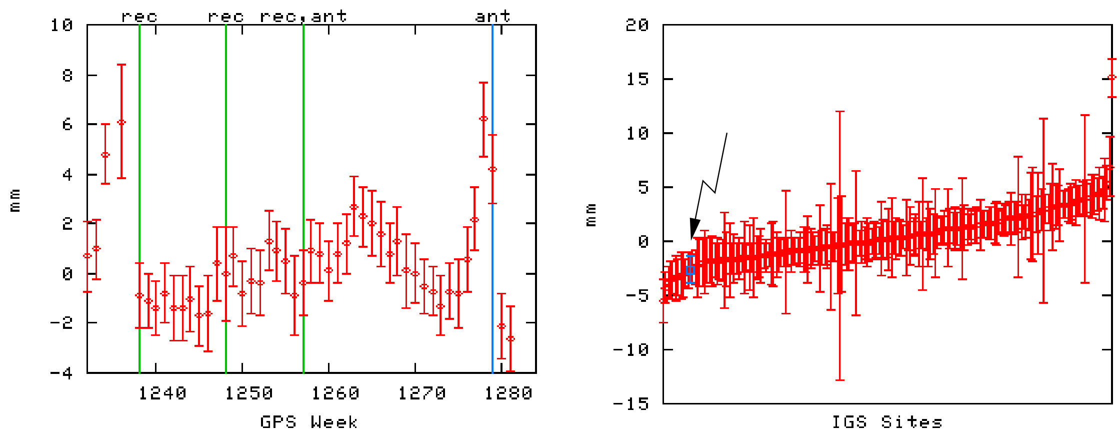

Figure 5: (left) Time series residual plot for station NRC1 noting an equipment change. (right) NRC1's most recent residual (value) and standard deviation of a year of residuals (error bars) compared to the rest of the IGS.

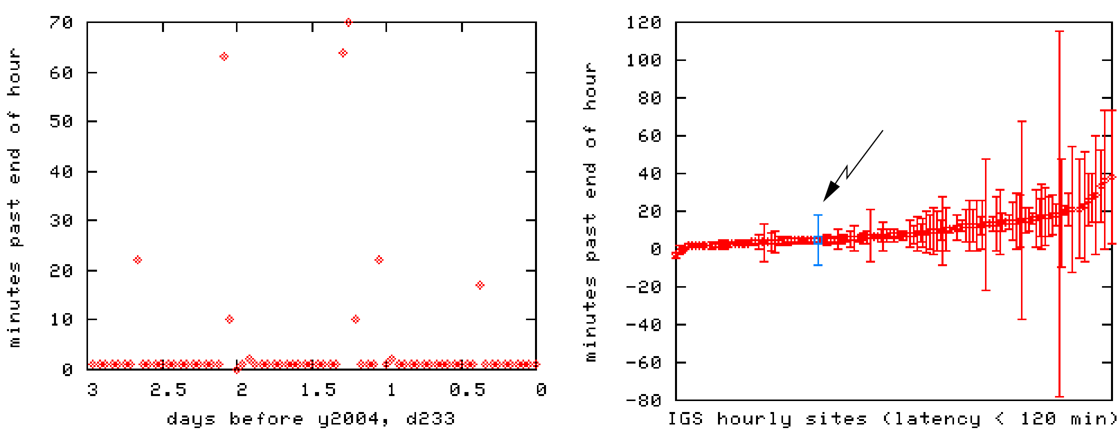

Figure 6: Recent hourly data latency for station YARR.

	CODE	NRCan	ESOC	GFZ	GOP	JPL	MIT	NOAA/NGS	SIO	USNO
Final Orbit:	X	X		X		X	X		X	
Rapid Orbit:	X	X		X		X				
Ultra Orbit:										
Final Clock:	X			X		X	X			
Rapid Clock:	X			X		X				
Final Trop:	X	X		X		X			X	
NRT Trop:										

Figure 7: Example of table presenting which IGS Analysis Centers have recently used data from a certain station.

reflecting current practice, and awareness of the importance and responsibilities of reference frame sites was not adequately highlighted.

A number of related documents were consulted, including previous IGS guidelines, EUREF Permanent Network guidelines, International Space Geodetic Network (ISGN) guidelines, various IGS pilot project guidelines, the Network position paper from the 2002 Ottawa Workshop “Toward Real-Time”, and archives of discussions within the IGS Reference Frame Working Group. The new IGS guidelines were designed to make clear what are non-negotiable strict requirements, and what is additionally desired above and beyond where feasible. The drafts were reviewed by G. Gendt (IGS Analysis Center Coordinator), C. Bruyninx (EUREF Permanent Network Coordinator), R. Ferland (IGS Reference Frame Coordinator), J. Ray (IGS Analysis Center/Reference Frame expert), W. Gurtner (author of previous version of guidelines), and C. Noll (DCWG chair)

Other IGS Chairs and experts on particular topics were also consulted for input on the requirements for special classes of sites such as those that contribute to particular IGS Pilot Projects. This process served as an example of how the Network Coordinator can utilize the expertise of usual and additional groups to advise in network matters.

The IGS Governing Board approved the new document at the 23rd meeting in San Francisco, USA and delegated update authority to the NC, with the proviso that the document will be maintained in a continuous improvement mode utilizing the advice of appropriate experts, and that the GB will be regularly advised of updates to the guidelines.

The IGS site guidelines are available in the Tracking Network area of the Central Bureau Information System, http://igscb.jpl.nasa.gov. A related checklist for proposing new sites is also available.

4 Acknowledgment

It is a privilege to work remotely with, and occasionally even meet, the many agencies and operators from all over the globe, whose commitment makes the IGS possible.

The Network Coordination portion of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The Central Bureau was fortunate to have two talented undergraduate student workers in 2003-2004. Peter N. Jeziorek and Eric W. Richardson contributed significantly to our accomplishments.

Maps were created with GMT[4].

[4] Wessel, P. and W. H. F. Smith, New, improved version of the Generic Mapping Tools released, *EOS Trans. AGU, 79*, 579, 1998

Additions	ASPA	Pago Pago, American Samoa, USA	
	BAIE	Baie Comeau, Canada	
	BAKE	Bake Lake, Canada	
	CHAN	Changchun, China	
	CNMR	Saipan, Mariana Island, USA	
	CRAO	Simeiz, Ukraine	
	DAKA	Dakar, Senegal	
	EURK	Eureka, Canada	
	GLPS	Puerto Ayora, Ecuador	Replacing GALA
	GMSD	Nakatane Town, Japan	
	GODZ	Greenbelt, USA	
	GUUG	Mangilao, Guam	
	HALY	Halat Ammar, Saudi Arabia	
	HERT	Hailsham, England, UK	Replacing HERP
	HLFX	Halifax, Canada	
	IENG	Torino, Italy	
	IRKM	Irkutsk, Russia	
	ISPA	Easter Island, Chile	Replacing EISL
	KIR0	Kiruna, Sweden	Was KR0G
	KUUJ	Kuujjuarapik, Canada	
	MAR6	Maartsbo, Sweden	Was MR6G
	MOBS	Melbourne, Australia	
	NAIN	Nain, Canada	
	NAMA	Namas, Saudi Arabia	
	NISU	Boulder, USA	
	NOVJ	Novosibirsk, Russia	
	OHI3	O'Higgins, Antactic Peninsula	Replacing OHIZ
	PETS	Petropavlovsk-Kamchatka, Russian Federation	
	PICL	Pickle Lake, Canada	
	QIKI	Qikiqtarjuaq, Canada	
	REUN	Le Tampon, France	
	SASK	Saskatoon, Canada	
	SASS	Sassnitz Island of Ruegen, Germany	
	SOLA	Solar Village, Saudia Arabia	
	SVTL	Svetloe, Russia	
	SYDN	Sydney, Australia	
	TEHN	Tehran, Iran	
	THU2	Thule Airbase, Greenland, Denmark	
	TUKT	Tuktoyaktuk, Canada	
	UNFE	Ferrara, Italy	
	USN3	Washington, DC, USA	Replacing USN1
	VALD	Val D'Or, Canada	
	VIS0	Visby, Sweden	Was VS0G
	WARN	Rostock-Warnemuende, Germany	
	YIBL	Yibal, Oman	
	ZWE2	Zwenigorod, Russia	Replacing ZWEN
Deletions	CARR	Parkfield, USA	
	NRC2	Ottawa, CA	NRC1 continues
	OS0G	Onsala, Sweden	Same station as ONSA
	THU1	Thule, Greenland, Denmark	Replaced by THU3, THU2
	USN1	Washington, DC, USA	Replaced by USN3

Table 1: IGS network composition changes during 2003-2004

Continuous GPS Network RUSEG/NEDA (Russia) in 2003-2004

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1. Note

This is the first document characterizing the RUSEG/NEDA GPS Network in the framework of the IGS annual report.

2. Densification and Operation of RUSEG/NEDA GPS Network in 1997-2004

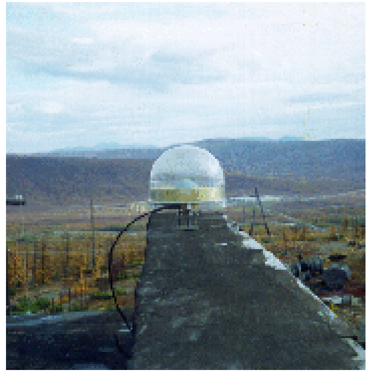
Continuous GPS Network of North Eurasia Deformation Array (RUSEG/NEDA) discussed in this Report is supervised by the Russian GPS Data Acquisition and Analysis Center / Geophysical Service of the Russian Academy of Sciences (RDAAC/GSRAS). Collaboration with International GNSS Service (IGS), Lamont-Doherty Earth Observatory of Columbia University (LDEO), Jet Propulsion Laboratory (JPL), and Incorporated Research Institutions for Seismology (IRIS) is very helpful.

By the end of 2004, the RUSEG/NEDA Network included eleven permanent GPS stations spanning all Russia, from Moscow to the Pacific Ocean and to the Arctic. See Table 1, and Figures 1 and 2. Stations ARTU, PETP, TIXI, and BILI are IGS Reference Frame sites. RUSEG/NEDA Network allowed us to make progress in understanding the kinematics of the Eurasian plate and its boundary with the North American plate in east Siberia [*Steblov et al.*, 2003]. Several regional projects in east Asia were also made possible due to the existence of the RUSEG/NEDA Network [*Bürgmann et al.*, 2005; *Kogan et al.*, 2003]. Nine stations of the RUSEG/NEDA Network share common internet channels with GSN seismic stations with which they are collocated (ARTU, YAKT, TIXI, MAG0, BILI, PETP, PETS, YSSK, MOBN). Internet connections for two stations, NRIL and IRKM, were established by RDAAC.

Table 1. *RUSEG/NEDA stations in Russia established in 1997-2004*

Station	**City/Village**	**Coordinates**			**Tectonic Location**	**Start and Mode of Operation**
		Lat N (°)	Lon E (°)	Elevation (m)		
YAKT	Yakutsk	62.031	129.681	100.064	Siberian Platform. Eurasian plate.	12-Nov-97 1-s rate
MAG0	Magadan	59.576	150.770	361.927	Okhotsk volcanic belt. North American plate.	12-Nov-97 30-s rate
PETP	Petro-pavlovsk	53.067	158.607	211.034	Kamchatka volcanic belt. North America – Pacific plate boundary.	14-Nov-97 30-s rate
PETS	Petro-pavlovsk	53.023	158.650	102.173	Kamchatka volcanic belt. North America – Pacific plate boundary.	23-Oct-92 1-s rate
TIXI	Tixi	71.634	128.866	46.985	Verkhoyansk fold-and-thrust belt, Eurasia - North America plate boundary	08-Oct-98 30-s rate
YSSK	Yuzhno-Sakhalinsk	47.030	142.717	91.289	Sakhalin Seismic Belt. Eurasia / North America plate boundary.	28-Jul-99 30-s rate
ARTU	Arti	56.430	58.560	247.511	Suture dividing Europe and Asia. Eurasian plate.	07-Aug-99 1-s rate
BILI	Bilibino	68.076	166.438	456.238	Chukotka Foldbelt. North American plate.	04-Sep-99 30-s rate
NRIL	Norilsk	69.362	88.360	47.916	Northern margin of Siberian platform. Eurasian plate.	17-Sep-00 1-s rate
MOBN	Moscow	55.115	36.570	182.482	East European platform. Eurasian plate.	08-Dec-00 1-s rate
IRKM	Irkutsk	52.219	104.316	502.324	Siberian Platform. Eurasian plate.	15-Aug-04 1-s rate

artu

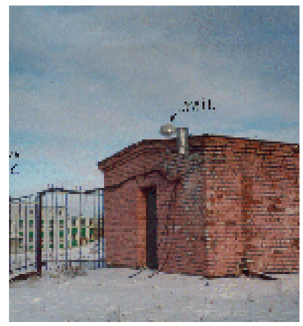


bili

irkm

mag0

mobn



nril

petp

pets

tixi

yakt

yssk

Fig. 1. Site photos.

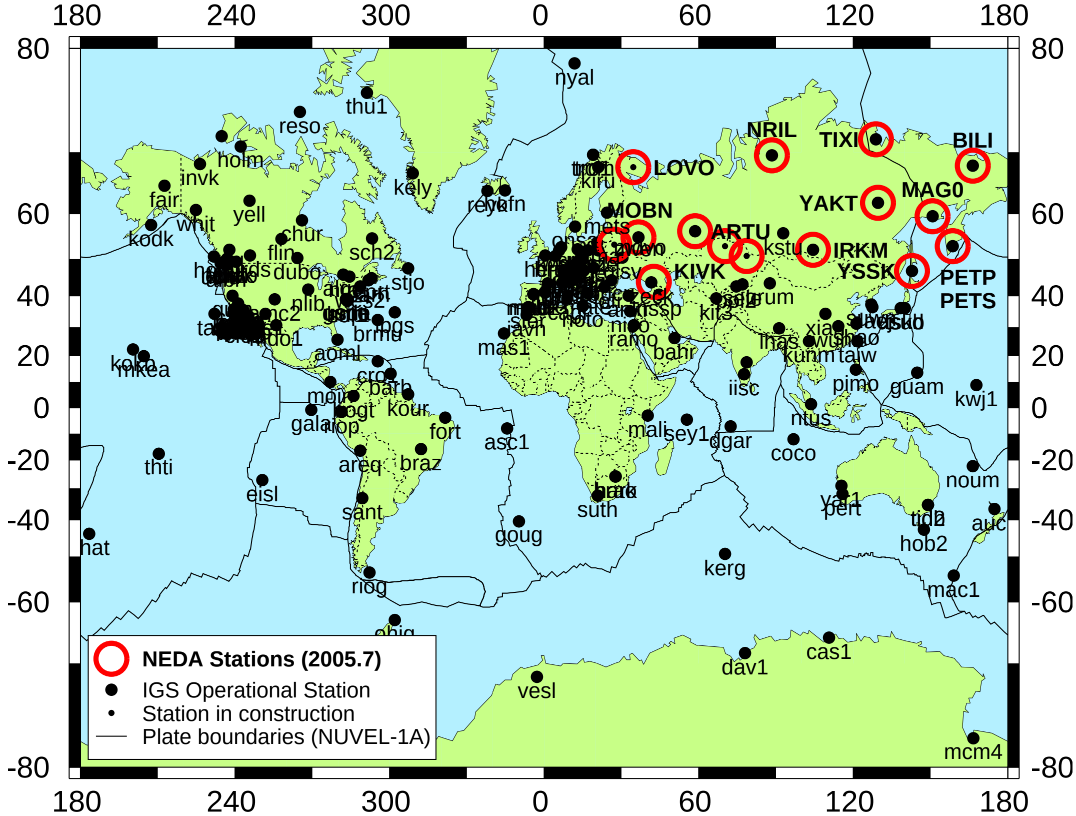


Fig. 2. Permanent Global IGS Network and its RUSEG/NEDA Segment.

All RUSEG/NEDA stations submit standard daily observation files (30-s sampling rate) by UTC midnight to IGS analysis centers. The latency of daily transfers is 10 min past UTC midnight. Stations ARTU, IRKM, and PETS submit, in addition, the hourly files. Other stations will start submitting hourly files in the near future. Stations ARTU, MOBN, NRIL, IRKM, YAKT, and PETS collect the data at 1-s sampling rate for purposes of seismology, and for projects with low earth orbiters (Figure 3).

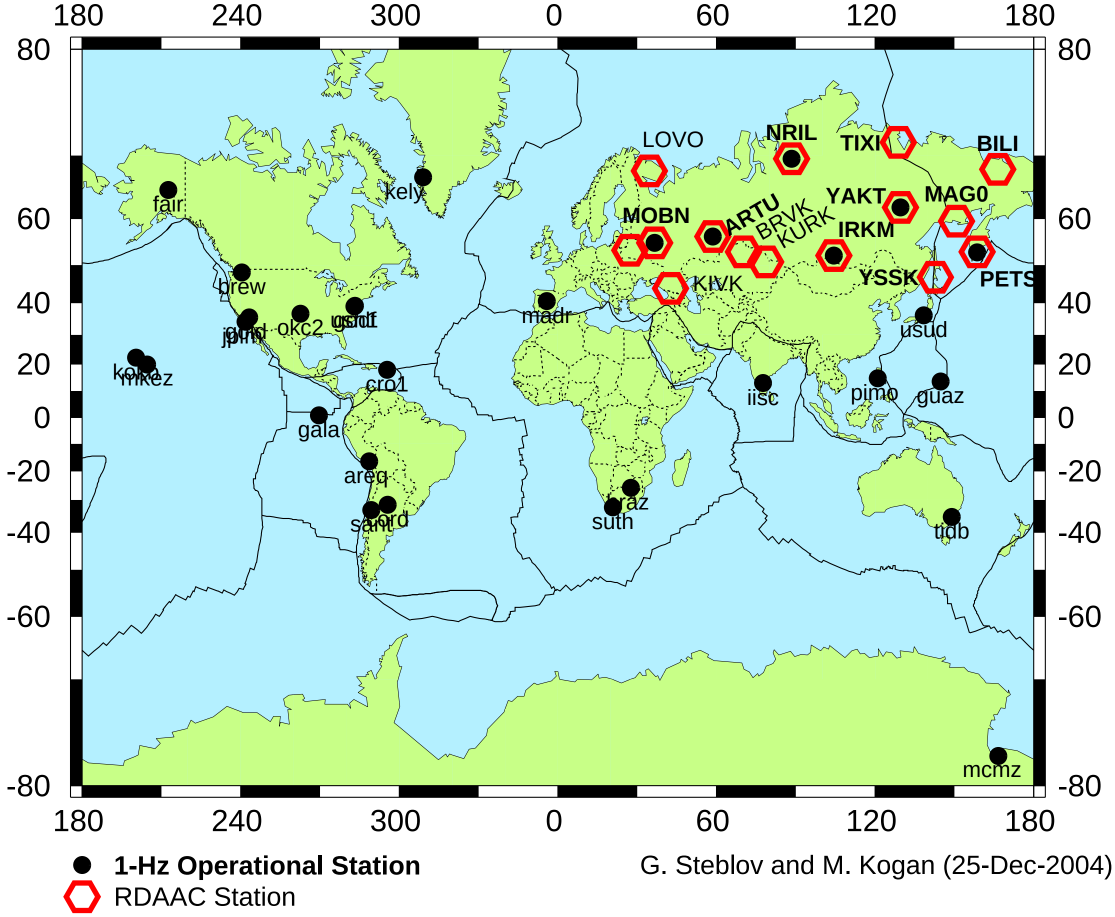


Fig. 3. 1-s Rate Global GPS Network and RUSEG/NEDA Segment

All RUSEG/NEDA stations are uniformly equipped with Thales Navigation Z-12 and micro-Z receivers and Ashtech choke-ring antennas. The receiver at station YAKT is controlled by the cesium frequency standard; the receiver at station IRKM is controlled by the H-maser (Figure 4). Download computers at all sites are running under Linux and are directly connected by internet to the server of RDAAC / GSRAS at Obninsk (Russia). Nine stations of the network are equipped with meteorological sensors Paroscientific MET3 (Figure 5). At seven stations (MAG0, MOBN, PETP, BILI, YSSK, NRIL, TIXI), the sensors are connected to GPS receivers. At two stations, ARTU and YAKT, the sensors are connected to station computers. All nine met sensors provide pressure/temperature/ humidity readings with 1- or 5-min sampling.

We designed the software to support the reliable automated retrieval of observations from the network via internet. Several alternative communication lines were implemented to ensure a secure uninterrupted data retrieval.

3. Overall Network Performance

GPS observations are collected at all RUSEG/NEDA stations in a timely manner and submitted to Analysis Centers (AC) with a small latency. More analysis centers are processing the observations collected over NEDA as compared with previous years. The meteorological data are now delivered to AC from nine stations. All Analysis Centers of the International GPS Service process the data collected at the RUSEG/NEDA Network to estimate station positions and velocities, orbits, clocks, state of the ionosphere, and the water vapor in the troposphere. The timely delivery of our observations allows the IGS to include them in the derivation of ultra-rapid, rapid, and final products (Table 2). It is worth noticing that since early 2003, station MOBN of the RUSEG/NEDA Network is the single station representing the East European Platform within the core IGS cluster, since earlier station ZWEN ceased to exist. The micro-Z receiver at station IRKM is connected to the same antenna as station IRKT (TurboRogue receiver) through the splitter. Eventually, IRKM supercede the aging receiver of IRKT. Both IRKM and IRKT are controlled by the same hydrogen maser, an external frequency reference.

Table 2. *Contribution of data collected at RUSEG/NEDA Network to the products of International GNSS Service: orbits (final, rapid, and ultra-rapid), clocks (final and rapid), tropospheric water vapor (final and near-real-time), and total electron content in the ionosphere (final).* **CODE***: Center for Orbit Determination in Europe, AIUB, Switzerland;* **NRCan***: Natural Resources Canada, Canada;* **ESOC***: European Space Operations Center, ESA, Germany;* **GFZ***: GeoForschungsZentrum, Germany;* **JPL***: Jet Propulsion Laboratory, USA;* **NOAA/NGS***: National Oceanic and Atmospheric Administration / NGS, USA;* **SIO***: Scripps Institution of Oceanography, USA;* **USNO***: U.S. Naval Observatory, US;* **MIT:** *Massachusetts Institute of Technology, USA.*

MOBN

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit					X				X
Rapid Orbit					X				
Ultra Orbit									
Final Clock					X				X
Rapid Clock					X				
Final Trop					X		X		
NRT Trop									
Final Iono					X				

ARTU

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit	X	X	X	X	X	X			X
Rapid Orbit	X	X	X	X	X	X		X	
Ultra Orbit	X	X	X	X			X		
Final Clock	X		X	X	X				X
Rapid Clock	X		X	X	X			X	
Final Trop	X	X	X	X	X	X	X		
NRT Trop		X		X			X		
Final Iono	X		X		X				

NRIL

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit	X	X		X	X	X			X
Rapid Orbit	X	X	X	X	X	X		X	
Ultra Orbit			X				X		
Final Clock	X			X	X				X
Rapid Clock	X		X	X	X			X	
Final Trop	X	X		X	X	X	X		
NRT Trop				X			X		
Final Iono	X		X		X				

YAKT

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit	X	X	X	X	X	X			X
Rapid Orbit		X	X		X	X		X	
Ultra Orbit		X	X						
Final Clock	X				X				X
Rapid Clock	X	X	X		X			X	
Final Trop	X	X			X	X	X		
NRT Trop									
Final Iono	X				X				

TIXI

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit		X	X	X	X	X			X
Rapid Orbit	X		X	X	X	X	X		
Ultra Orbit			X						
Final Clock	X		X	X	X				X
Rapid Clock	X		X	X	X				
Final Trop	X			X	X	X	X		
NRT Trop									
Final Iono	X		X		X				

MAG0

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit	X			X	X				X
Rapid Orbit	X				X	X			
Ultra Orbit									
Final Clock	X				X				X
Rapid Clock	X				X				
Final Trop	X				X		X		
NRT Trop									
Final Iono	X		X		X				

BILI

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit	X	X	X	X	X	X			X
Rapid Orbit	X	X	X	X	X	X		X	
Ultra Orbit			X						
Final Clock	X			X	X				X
Rapid Clock	X		X	X	X			X	
Final Trop	X	X		X	X	X	X		
NRT Trop									
Final Iono	X		X		X				

PETP

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit		X	X	X	X	X			X
Rapid Orbit		X	X	X	X	X		X	
Ultra Orbit			X						
Final Clock	X			X	X				X
Rapid Clock	X		X	X	X			X	
Final Trop		X		X	X	X	X		
NRT Trop									
Final Iono	X		X		X				

YSSK

	CODE	NRCan	ESOC	GFZ	JPL	NOAA /NGS	SIO	USNO	MIT
Final Orbit	X			X	X	X			X
Rapid Orbit	X	X		X	X				
Ultra Orbit									
Final Clock	X			X	X				X
Rapid Clock	X			X	X				
Final Trop	X			X	X		X		
NRT Trop									
Final Iono	X		X		X				

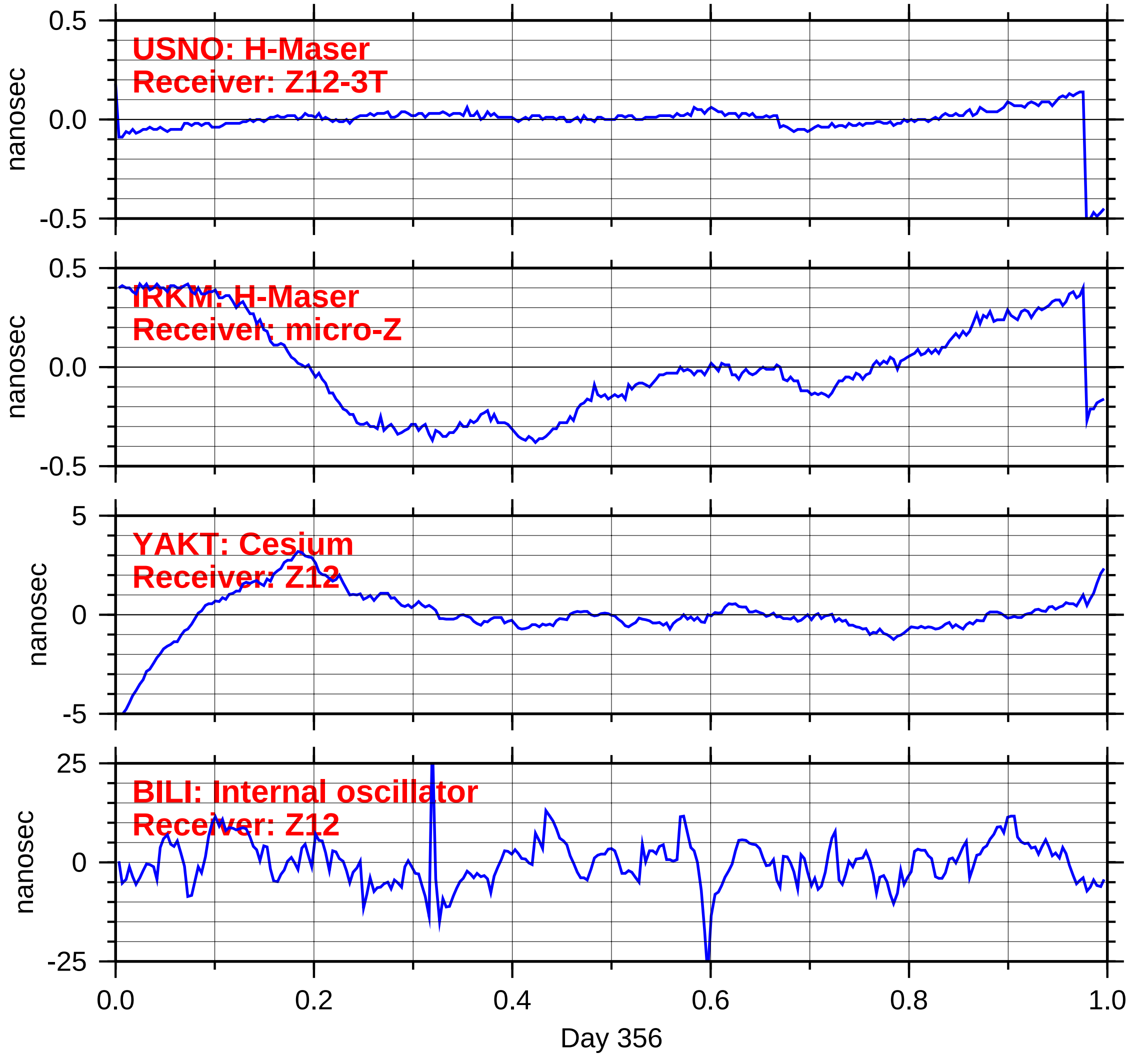


Fig. 4. Solution for station clocks on day 2004: 356 for a reference station USNO (combined with reference stations ALGO, NLIB, WES2, and PIE1), and RUSEG/NEDA stations IRKM, YAKT, and BILI.

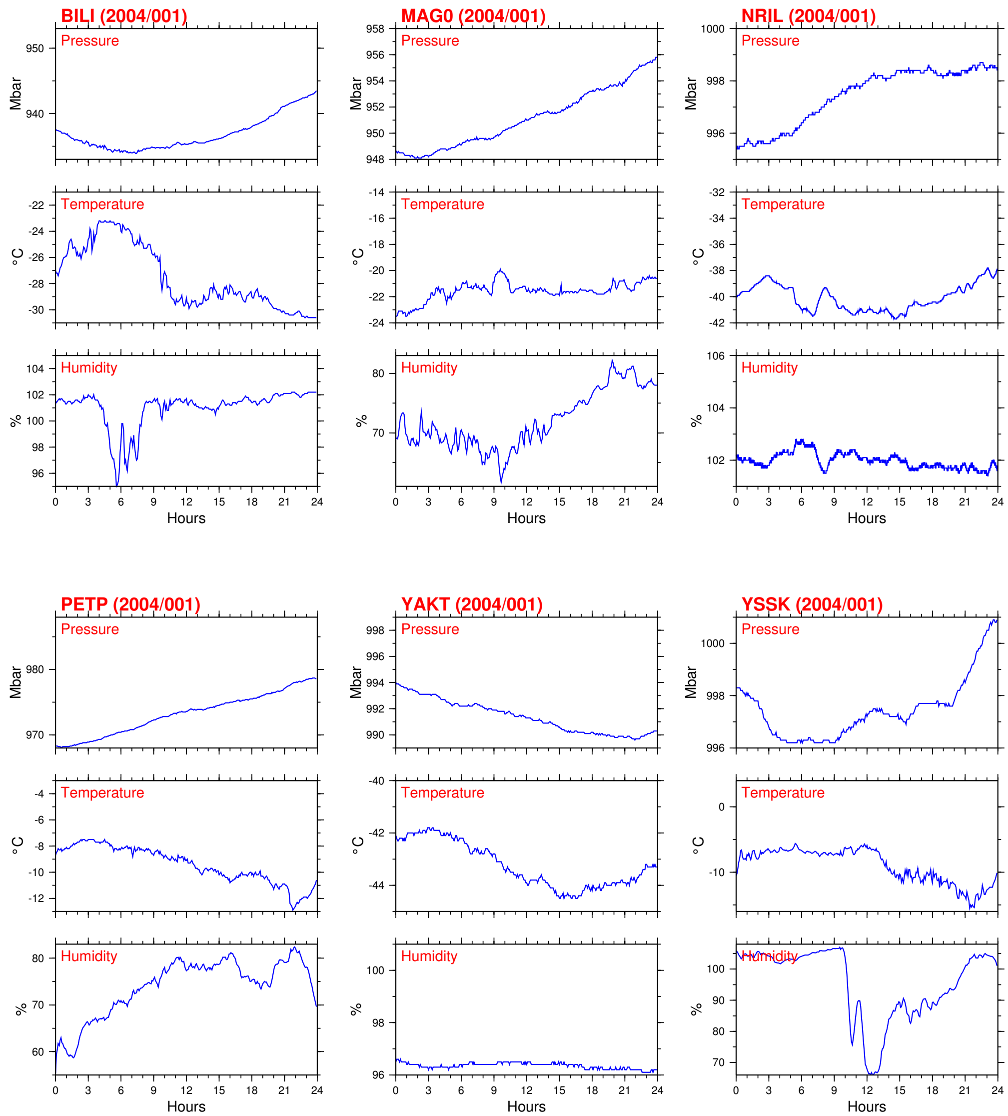


Fig. 5a. Temperature, pressure, and humidity at selected RUSEG/NEDA GPS stations, sampled with the met sensors; day 2004: 001

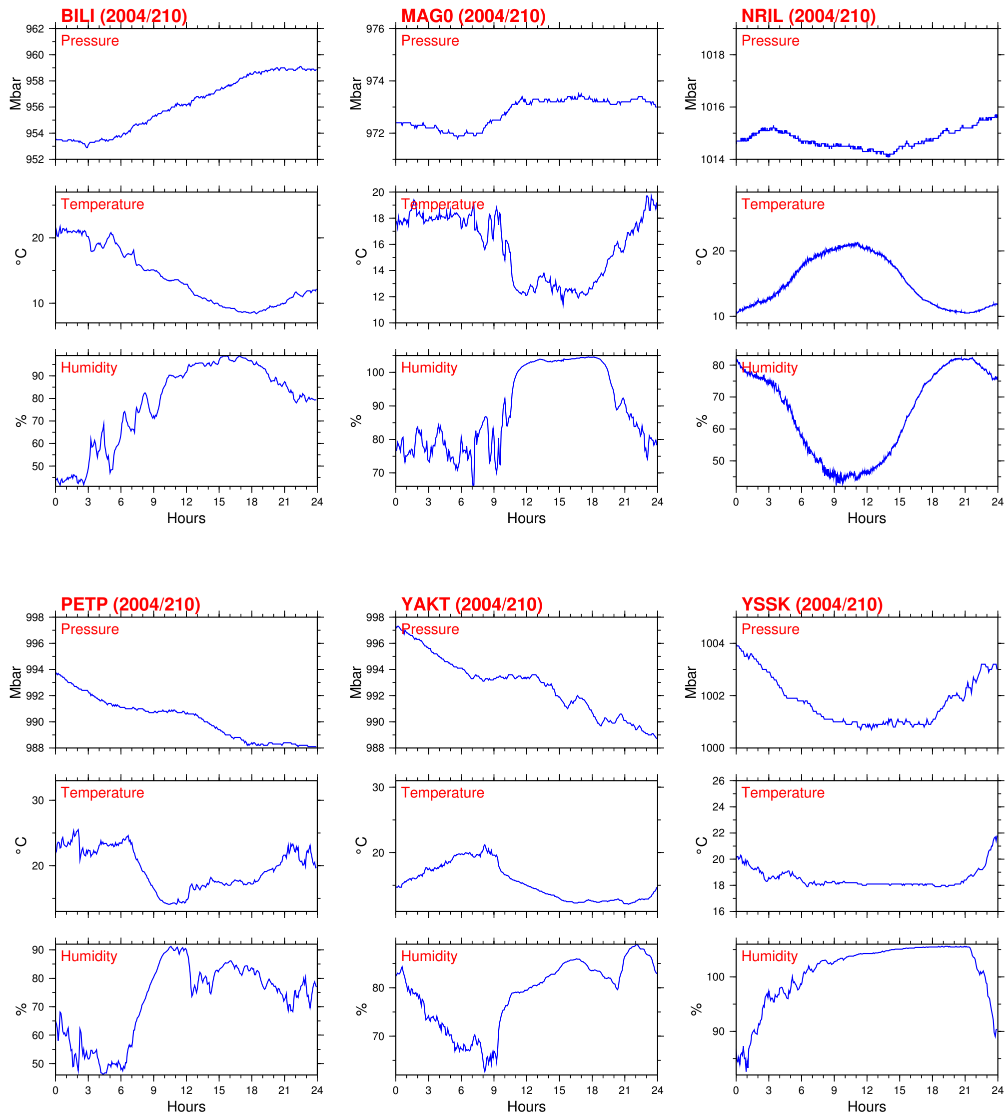


Fig. 5b. Temperature, pressure, and humidity at selected RUSEG/NEDA GPS stations, sampled with the met sensors; day 2004: 210.

4. Short-period Noise in Observations

We routinely monitor the quality of observations from daily processing by GAMIT/GLOBK software [*Herring*, 2005; *King and Bock*, 2005]. At each station, the phase residuals are estimated for individual satellites as a convenient indicator of multipath (Fig. 6). The 1-sigma variation for all stations except YAKT is in the range 6-10 mm which agrees with the typical noise at most of IGS stations. At YAKT, the variation is about twice higher. The variations as a function of time repeat with a period of a sidereal day (compare Figures 6j and 6k), a clear indication of multipath.

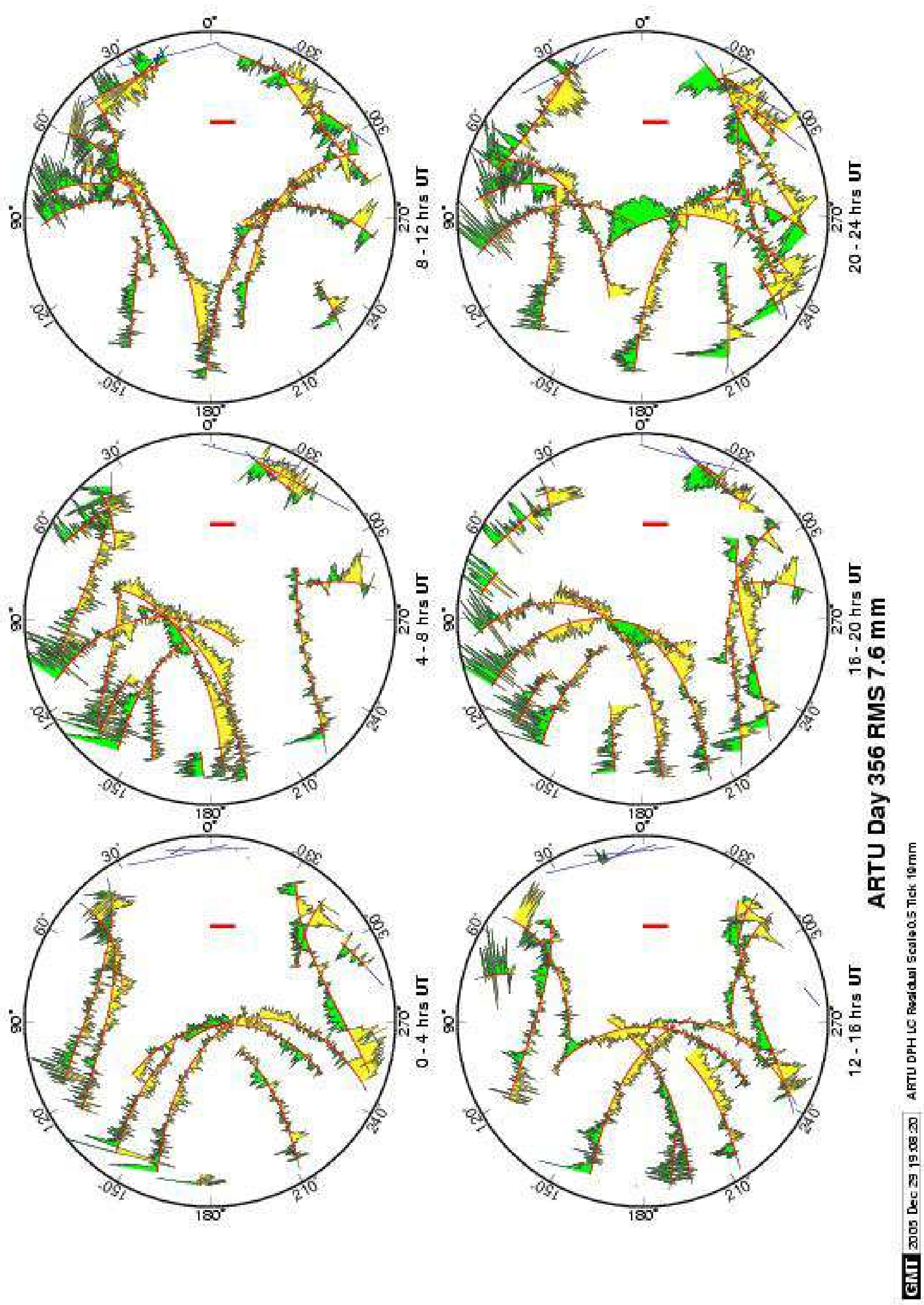


Fig.6a. Phase residuals (mm) at station ARTU for individual satellites. Day 2004:356

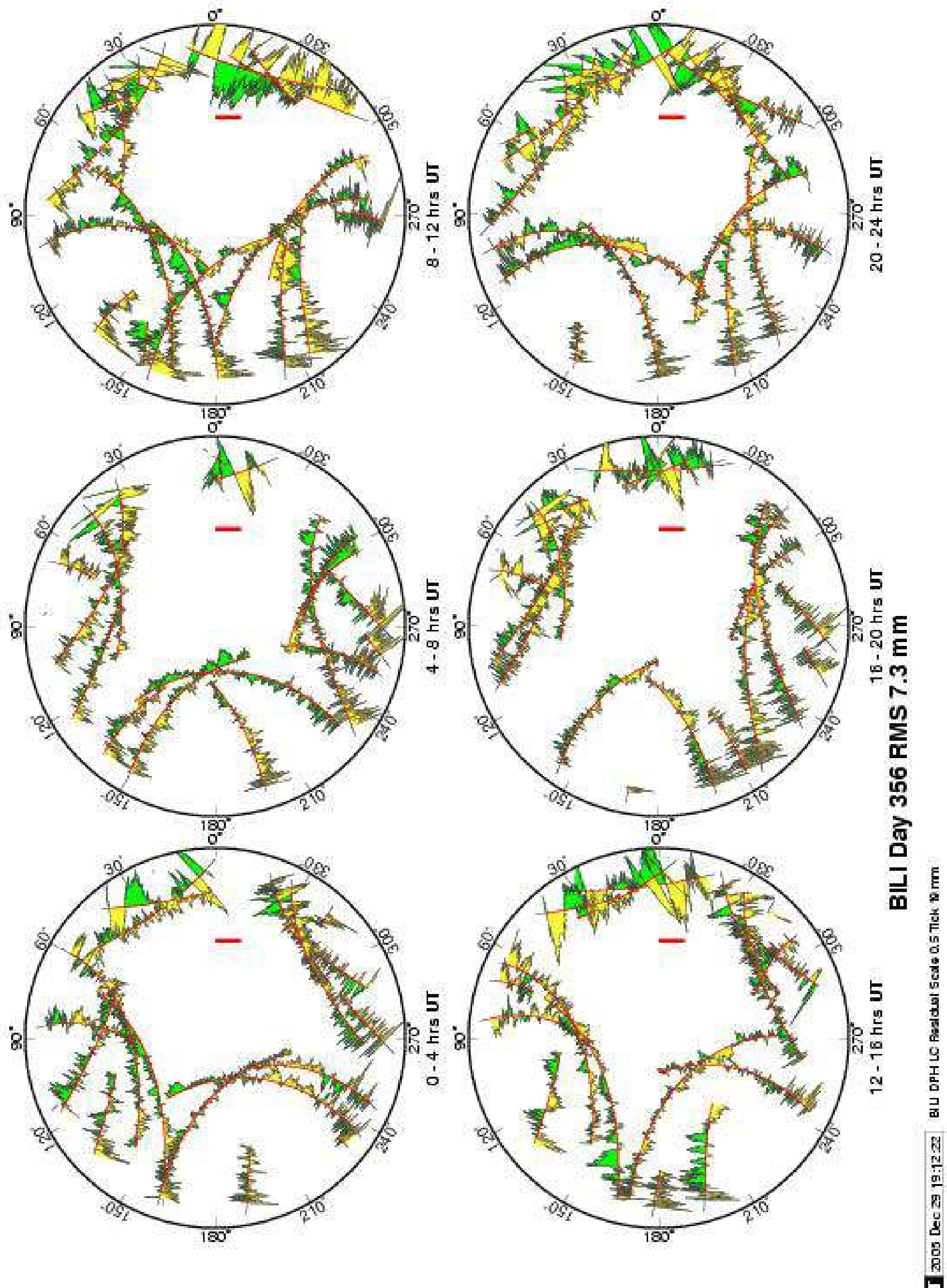


Fig.6b. Phase residuals (mm) at station BILI for individual satellites. Day 2004:356

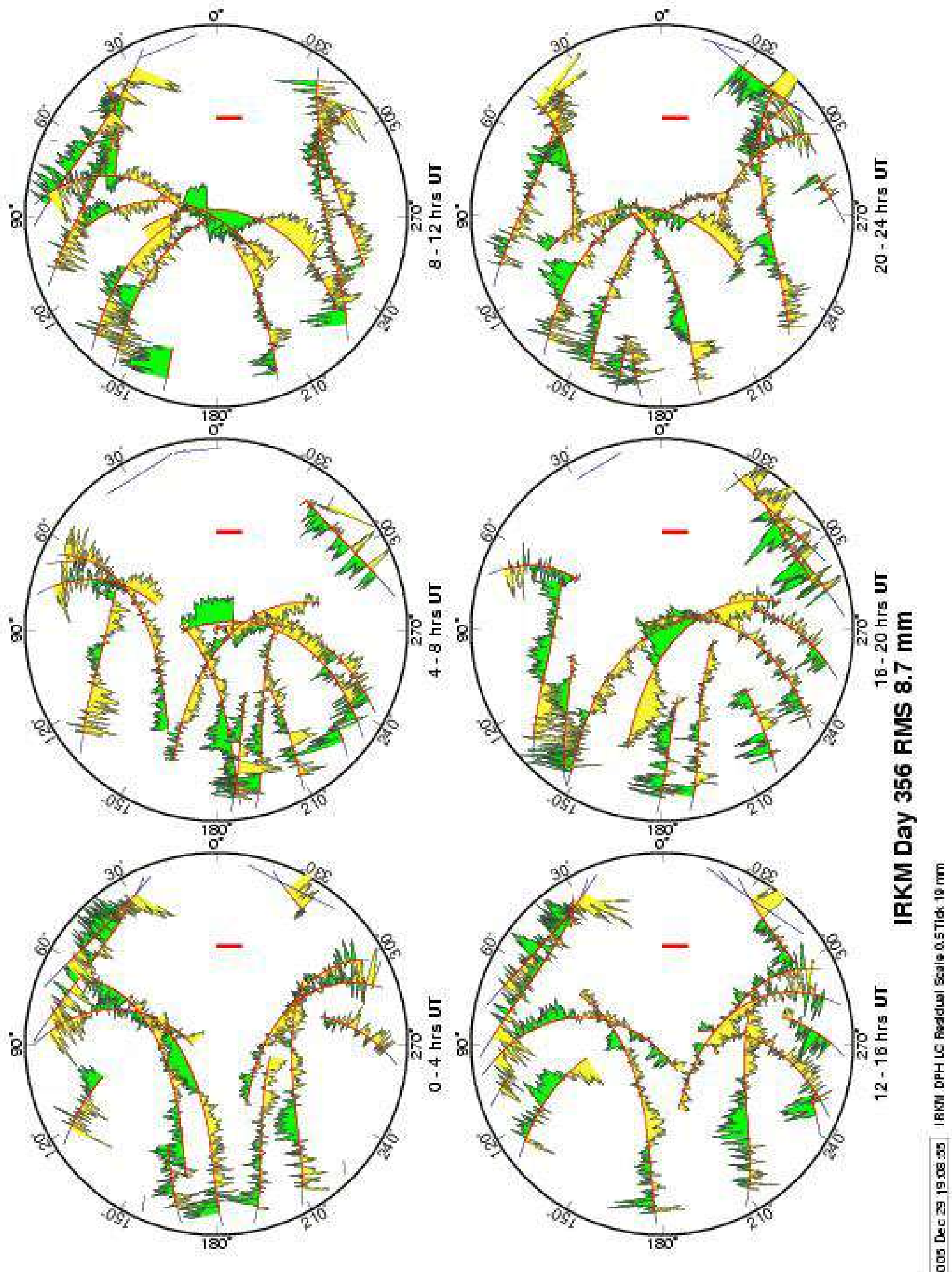


Fig.6c. Phase residuals (mm) at station IRKM for individual satellites. Day 2004:356

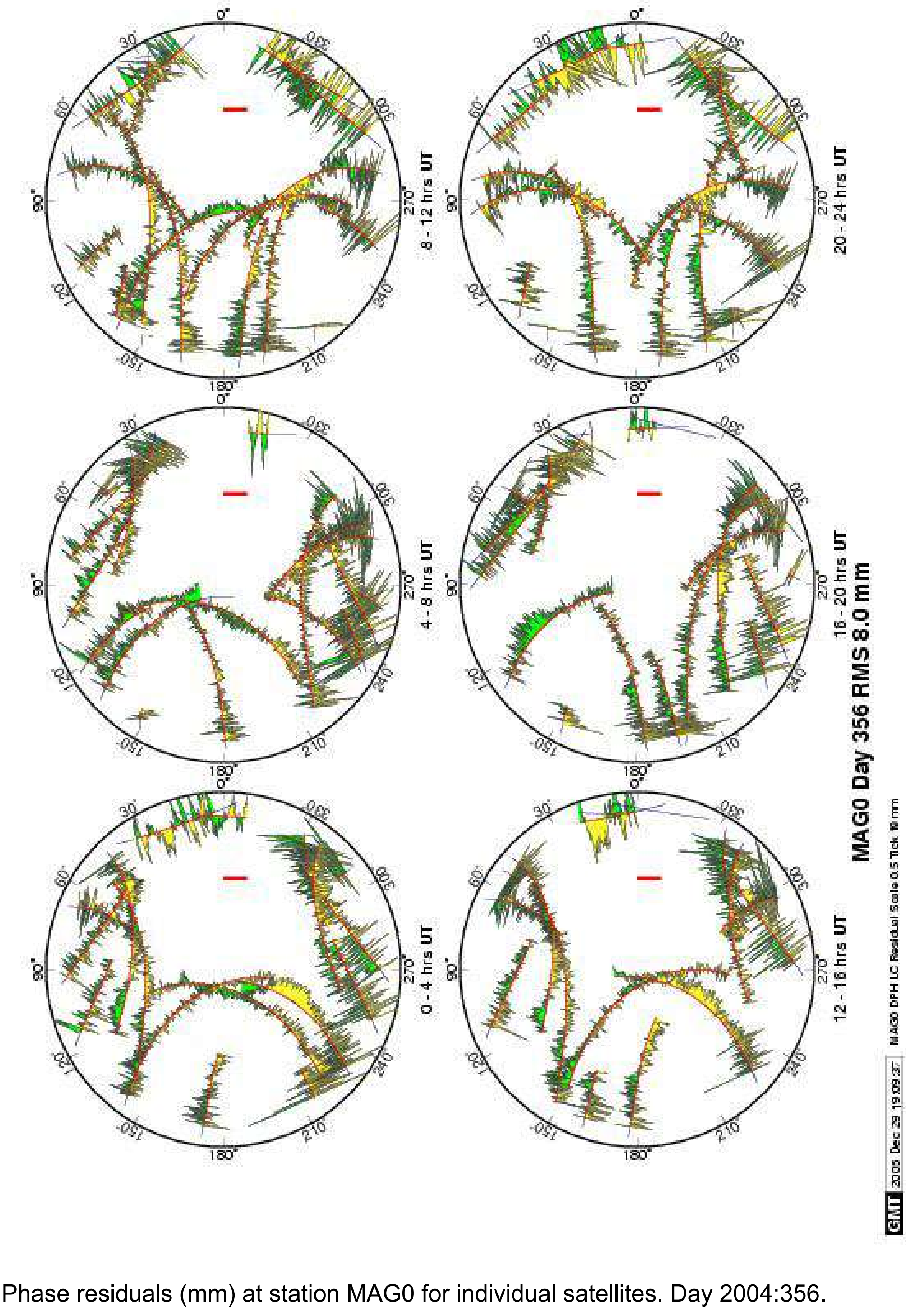


Fig.6d. Phase residuals (mm) at station MAG0 for individual satellites. Day 2004:356.

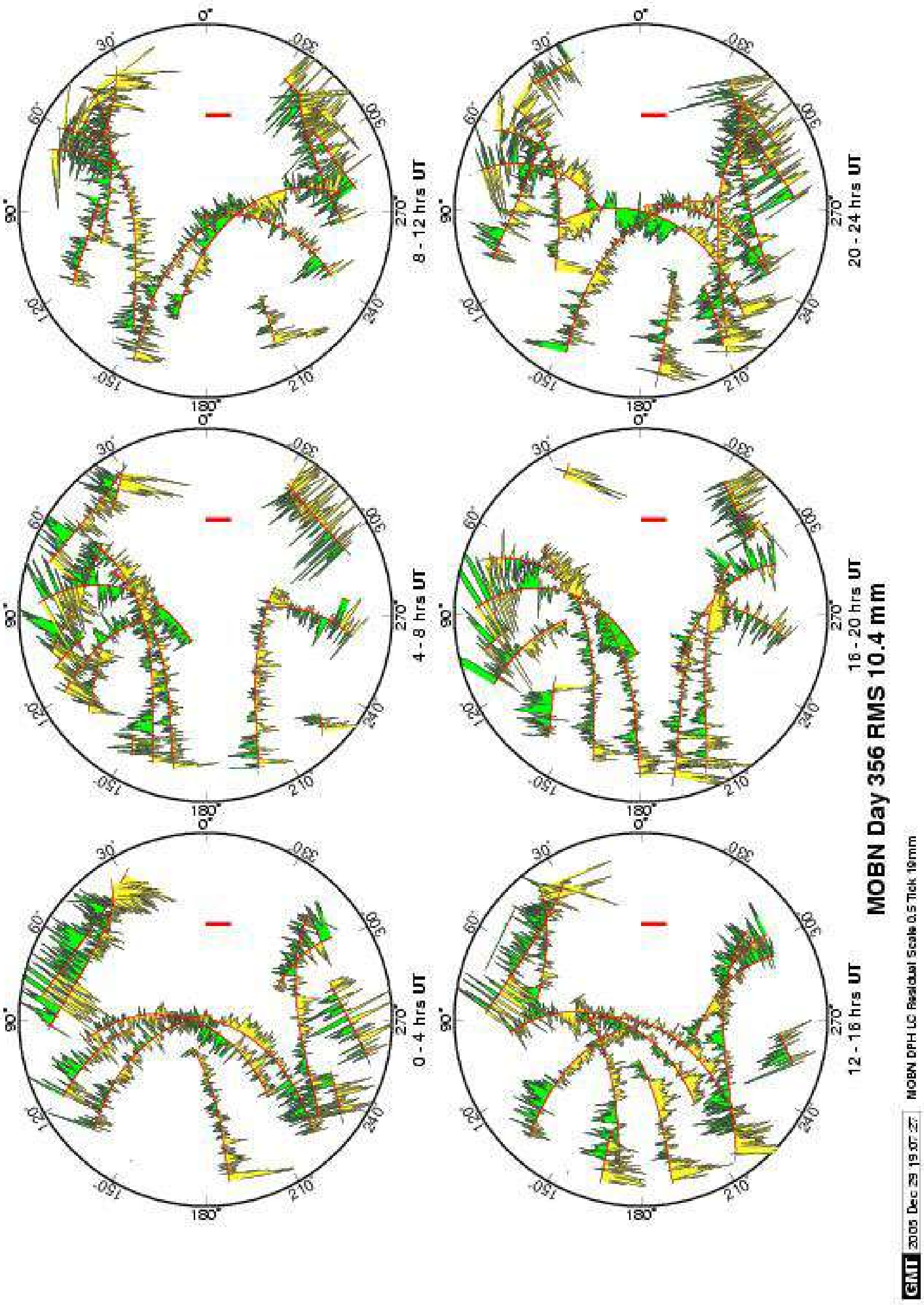


Fig.6e. Phase residuals (mm) at station MOBN for individual satellites. Day 2004:356.

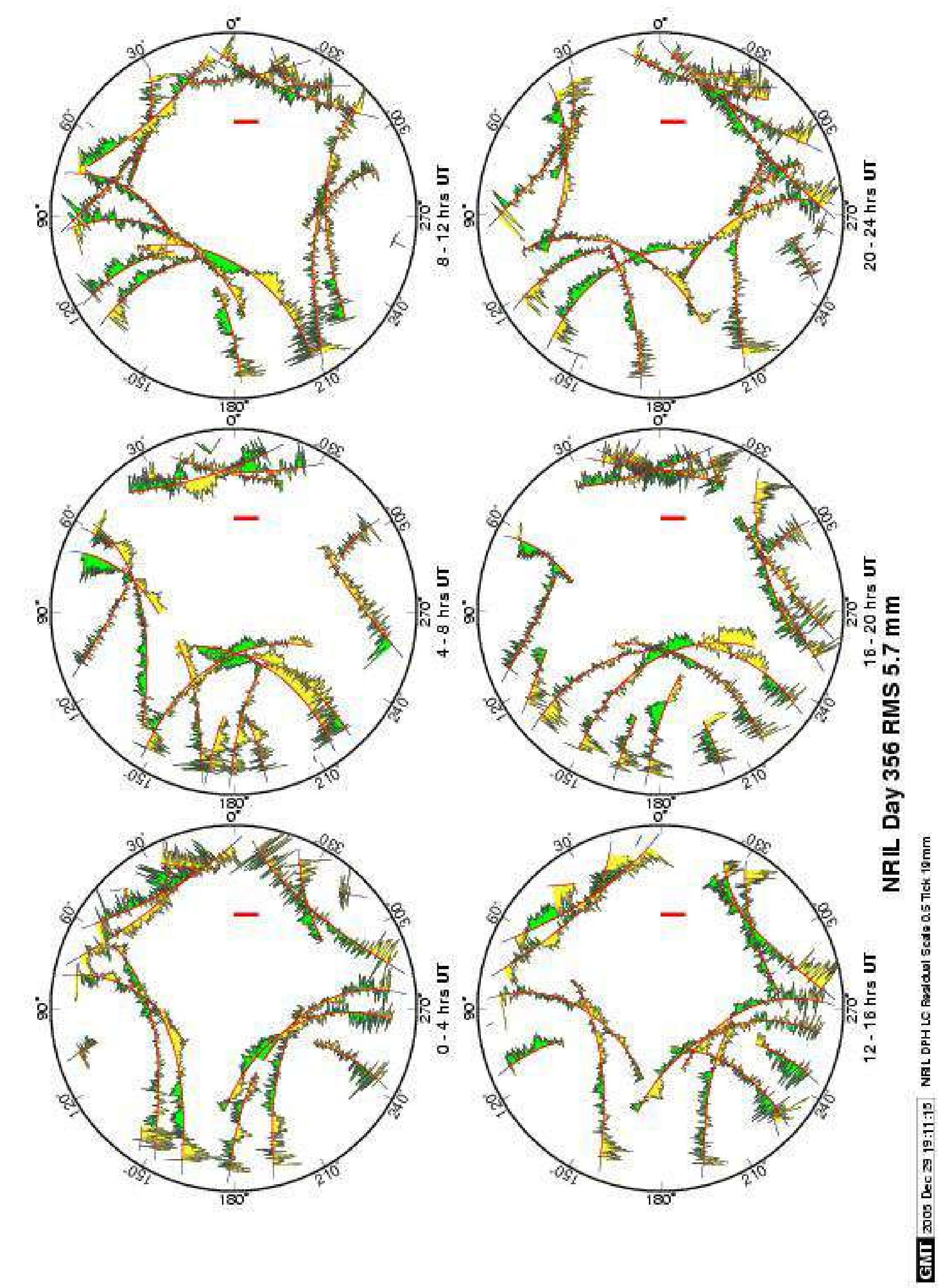


Fig.6f. Phase residuals (mm) at station NRIL for individual satellites. Day 2004:356.

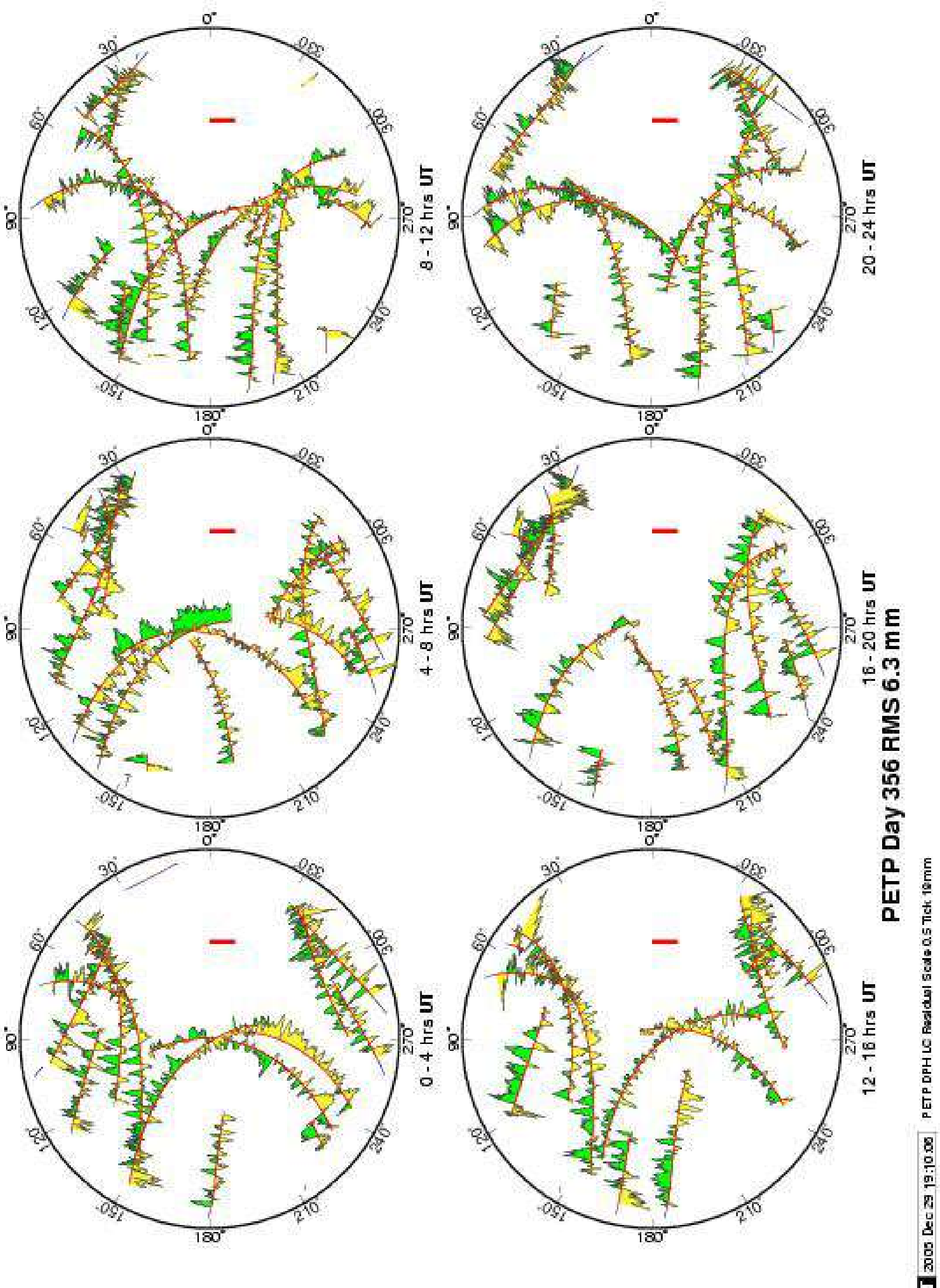


Fig.6g. Phase residuals (mm) at station PETP for individual satellites. Day 2004:356.

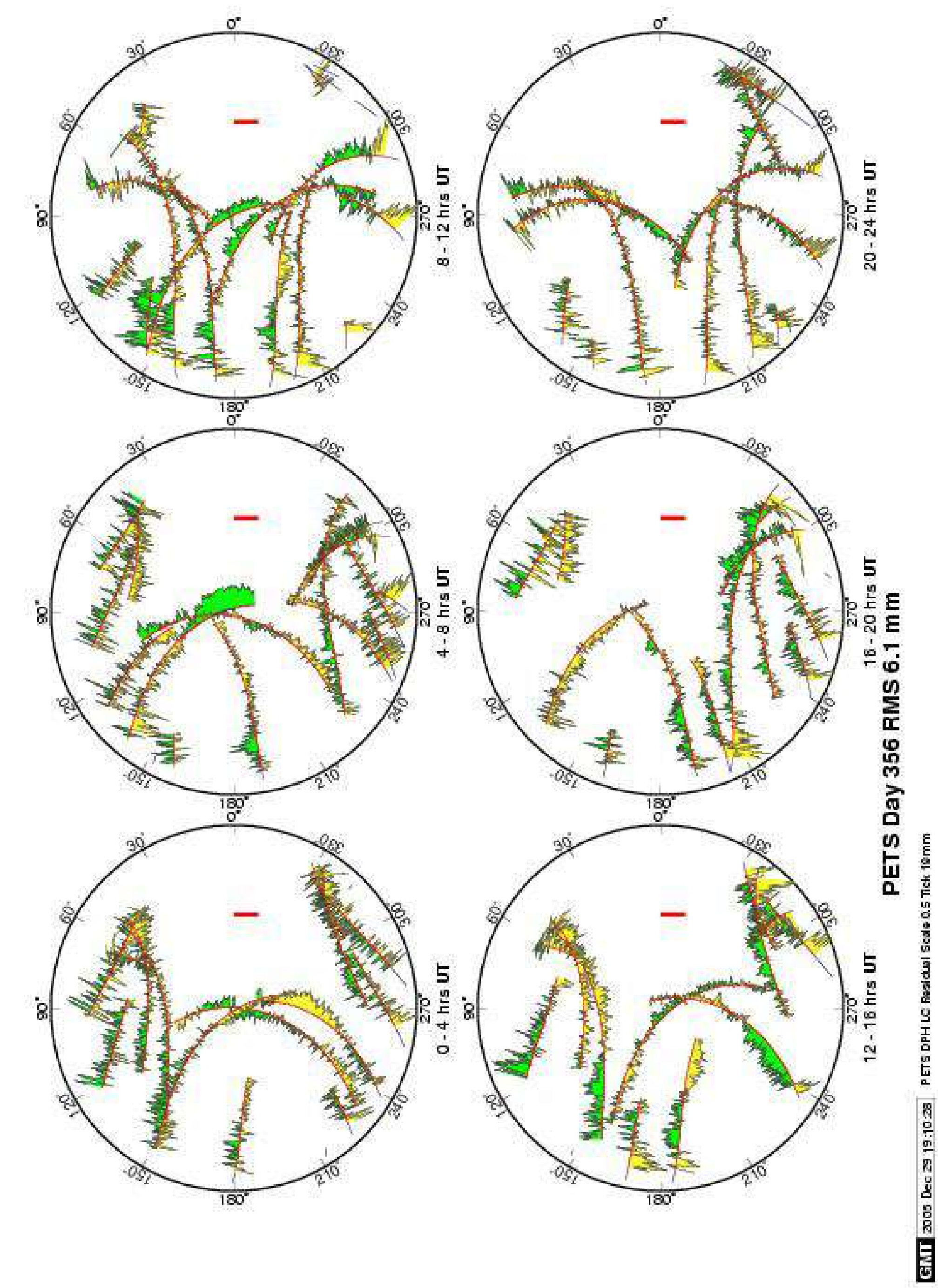


Fig.6h. Phase residuals (mm) at station PETS for individual satellites. Day 2004:356.

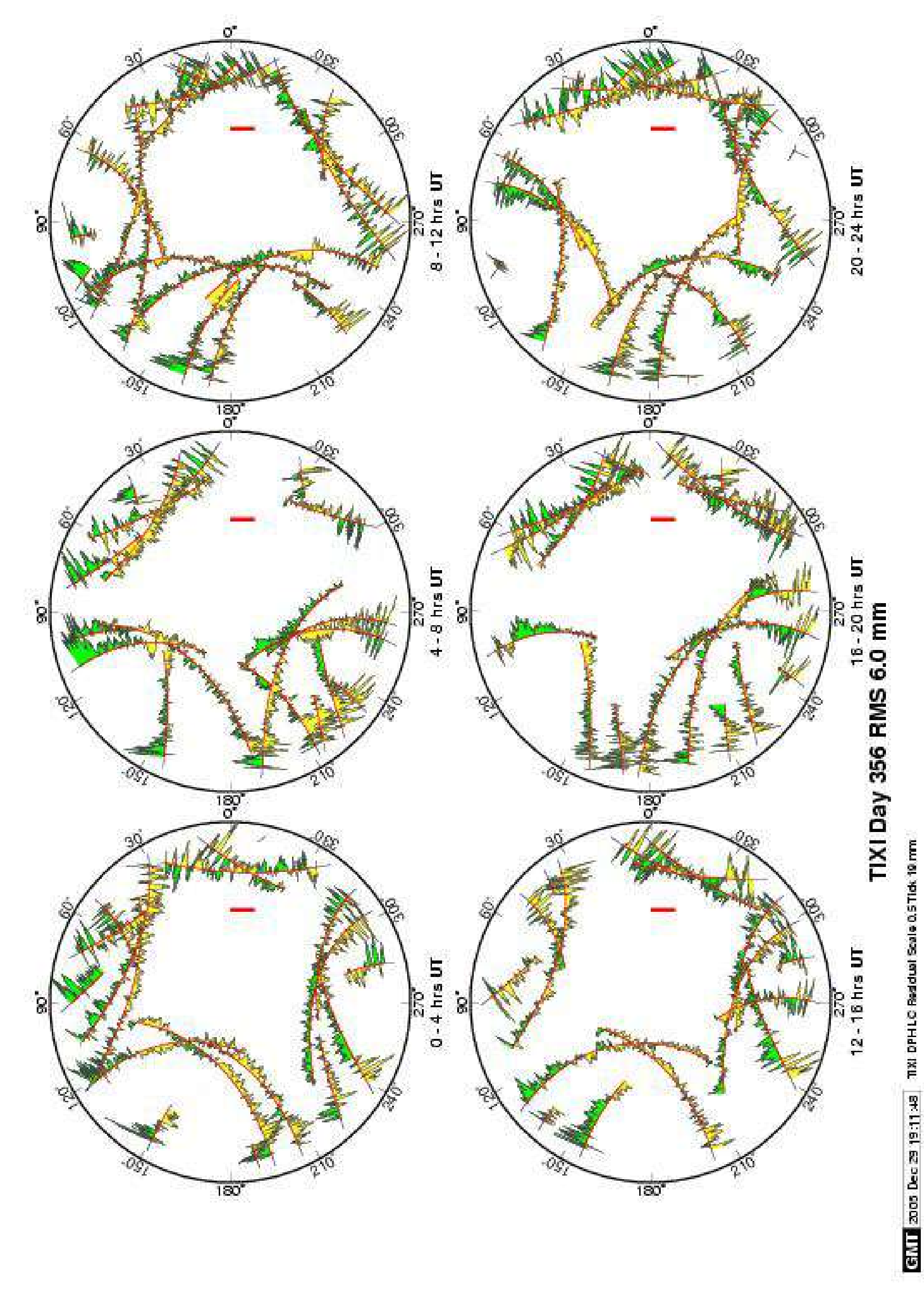


Fig.6i. Phase residuals (mm) at station TIXI for individual satellites. Day 2004:356.

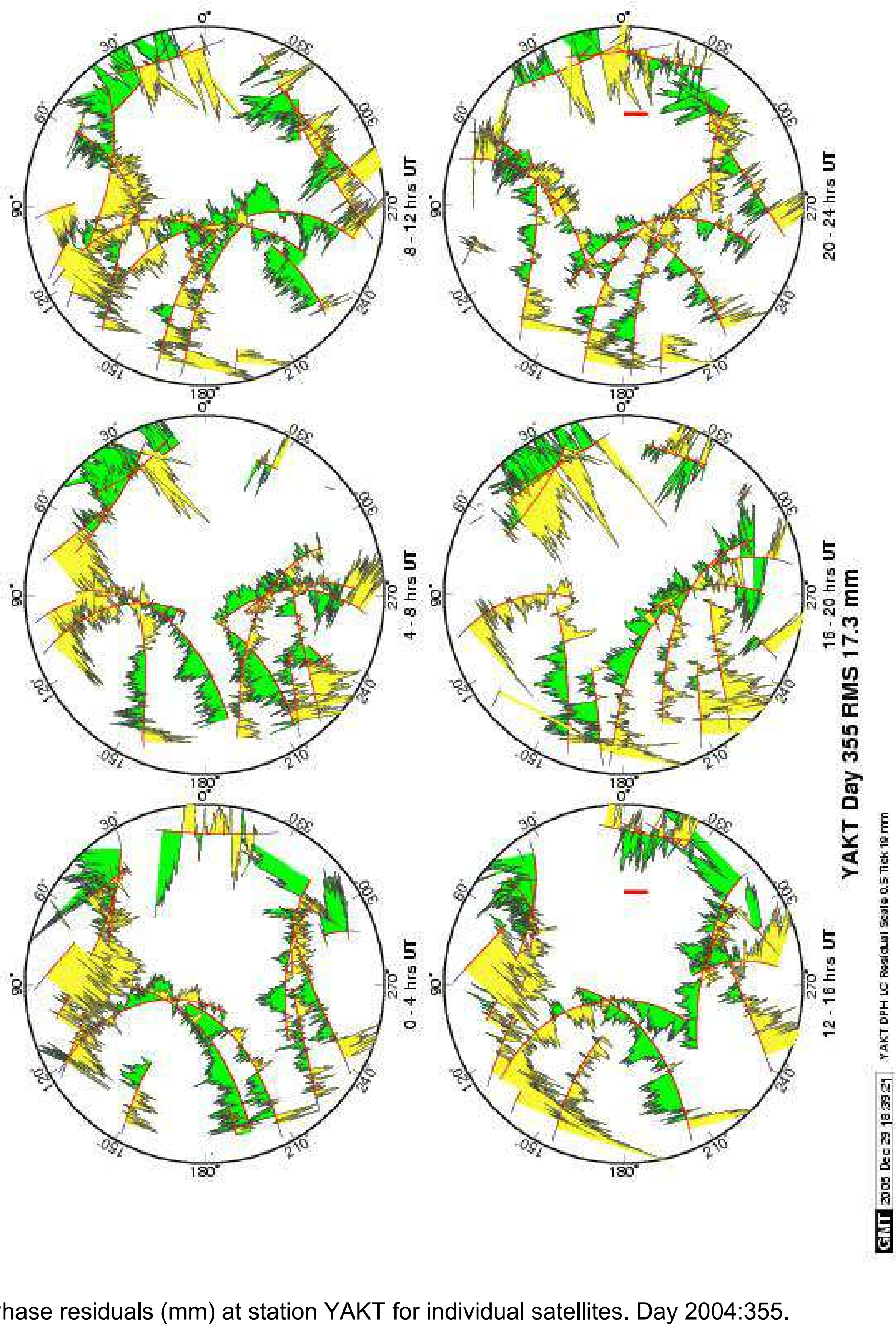


Fig.6j. Phase residuals (mm) at station YAKT for individual satellites. Day 2004:355.

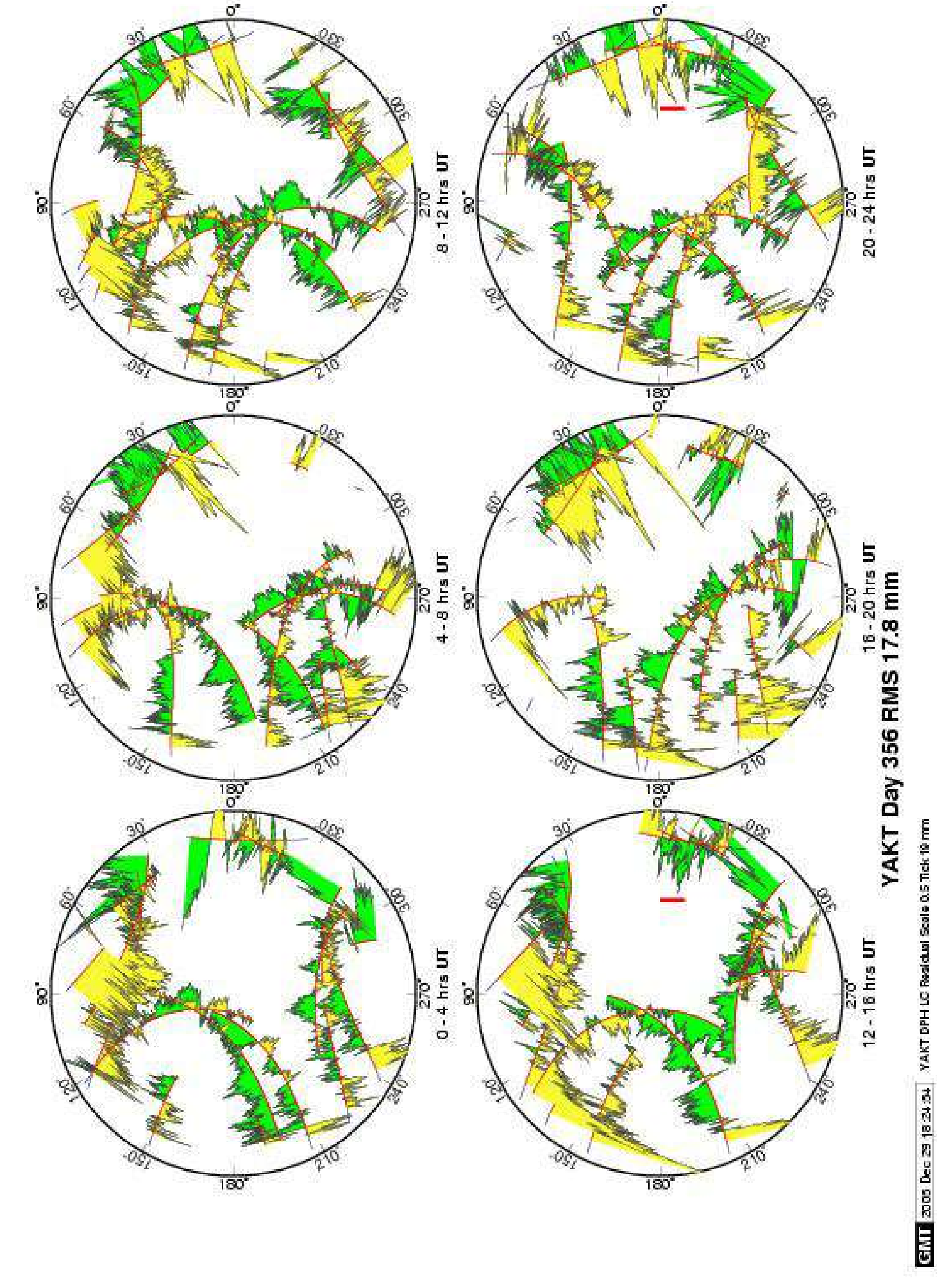


Fig.6k. Phase residuals (mm) at station YAKT for individual satellites. Day 2004:356.

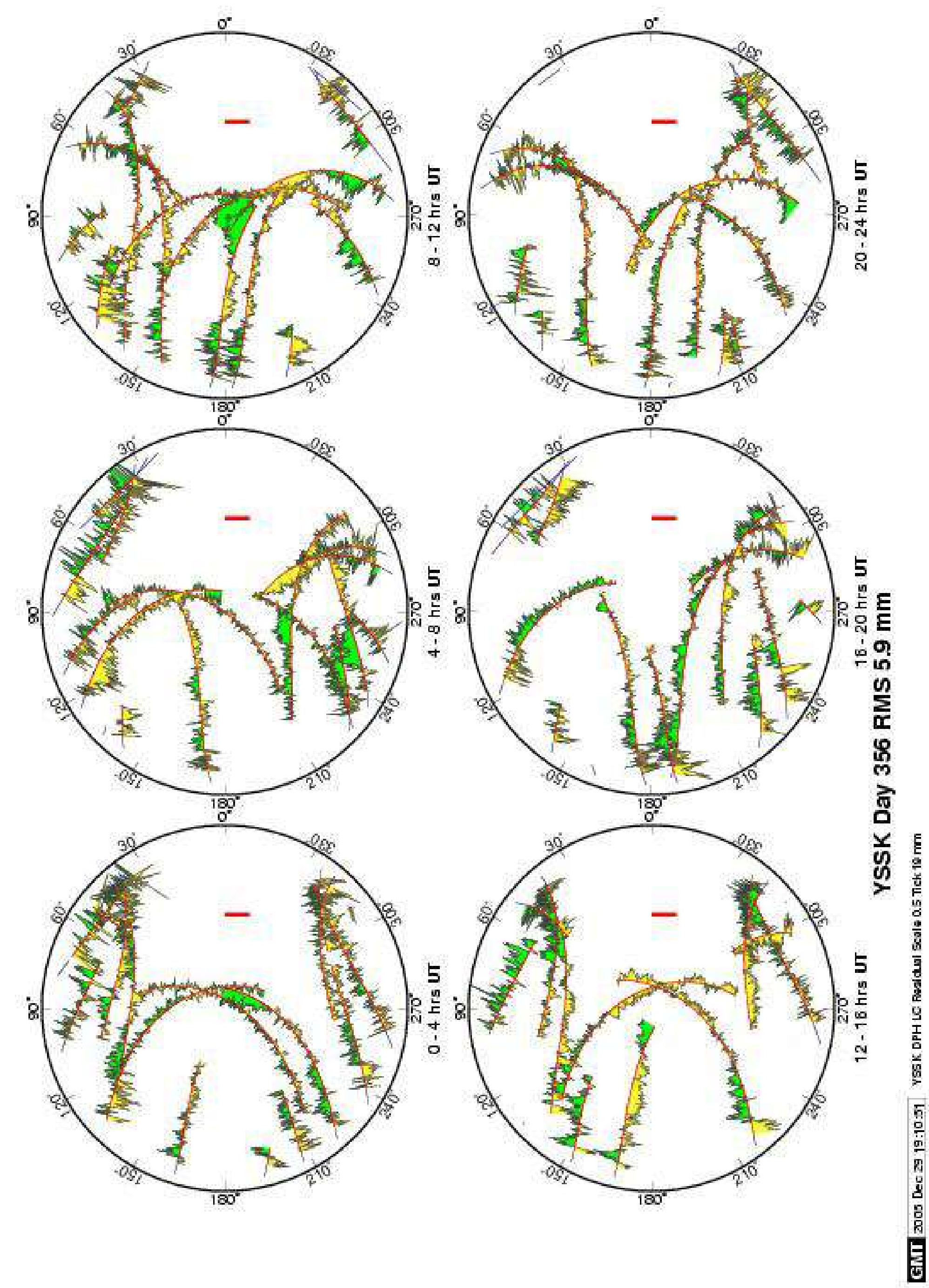


Fig.6l. Phase residuals (mm) at station YSSK for individual satellites. Day 2004:356.

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Network Operations and Data Flow within the EPN

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Introduction

The EUREF Permanent Network (EPN) is a European network of GPS tracking stations, data centers and analysis centers all contributing on voluntary basis. Its main goal is the maintenance and realization of the European Terrestrial Reference System (ETRS89). A large part of the EPN stations also contributes to the IGS.

Growth of the Tracking Network

The EPN tracking network has continued to operate successfully during the period 2003-2004 and it integrated 30 new stations in its network (see Figure 1); 4 stations were removed from the network:

BUDP	København, Denmark	H					
BUTE	Budapest, Hungary	H		IP			
CAGZ	Cagliari, Italy	H		IP		GLO	IGS
COMO	Como, Italy	H					
DARE	Daresbury, England	H					
GANP	Ganovce, Slovakia	H					
HERT	Hailsham, England	H	TG	IP		GLO	IGS
HOER	Hoernum, Germany	H		IP		GLO	
IENG	Torino, Italy	H			TL		IGS
IGD1	Athens, Greece	H					
INVE	Inverness, Great Britain						
JOZ2	Jozefoslaw, Poland	H		IP		GLO	IGS
KATO	Katowice, Poland	H					
KRAW	Krakow, Poland	H		IP			
MSEL	Medicina, Italy						
NEWL	Newlyn, England		TG				
OBET	Wessling, Germany				TL		IGS
PLYM**	Plymouth, England						
PRAT	Prato, Italy	H					
REDU	Redu, Belgium	H					
SASS	Sassnitz, Germany	H	TG	IP		GLO	IGS
SKE0	Skellefteaa, Sweden	H	TG			GLO	
SMID	Smidstrup, Denmark	H					
SULD	Suldrup, Denmark	H					
TARS	Taranto, Italy	H					
TUC2	Chania, Greece	H					

THU3*	Thule, Greenland	H					IGS
WARN	Warnemunde, Germany	H	TG	IP		GLO	IGS
ZOUF	Cercivento, Italy	H					
ZYWI	Zywiec, Poland	H					

With

H	:	Station submitting hourly data
TG	:	TIGA station
IP	:	EUREF-IP station
TL	:	Station collocated with a TAI Time Laboratory
GLO	:	GPS/GLONASS station
IGS	:	IGS station
*	:	Replacement of existing EPN station
**	:	Removed again before the end of 2004

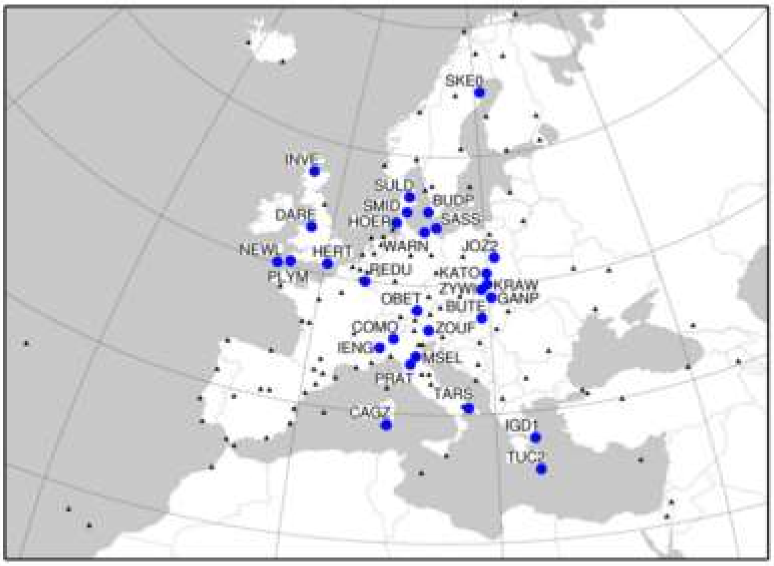

Figure 1 – EPN tracking network (big circles show stations added to the network in 2003-2004)

New guidelines for EPN stations

The step-wise procedure that assists candidate EPN stations during their integration into the EPN has been revised in Dec. 2003. The most important change concerns the new requirement to submit a commitment letter guaranteeing that the station will be operated following EPN guidelines for a minimal period of 5 year. The new "Procedure for becoming an EPN station" can be downloaded via: http://www.epncb.oma.be/_organisation/guidelines/procedure_becoming_station.html

The IGS issued in 2004 new guidelines for its stations and also within the EPN the introduction of new guidelines for EPN stations and operational centers became necessary. The updated IGS guidelines have been a starting point for the creation of the new EPN guidelines. The final version of the guidelines was approved by the EUREF Technical Working Group (TWG) on Nov. 30, 2004 and distributed through EUREF mail to the EPN network components on 14 Dec. 2004. The guidelines are on-line available at: http://www.epncb.oma.be/_organisation/guidelines/.

Data Flow

The most important change in the EPN guidelines is related to the data flow. In order to improve the availability of the EPN data at the regional level (especially important for EPN stations also contributing to the IGS), all EPN stations should make their data available at two regional data centers (RDC): BKG (Federal Office of Cartography and Geodesy, Germany) and OLG (Space Research Institute, Austrian Academy of Sciences). Under normal conditions, BKG will routinely upload the relevant EPN data to the IGS. However, in case of a failure at BKG, OLG will take over this upload assuring no interruption in the data upload to the IGS.
It is imperative that two independent data flow paths are used to upload the EPN data to the two RDCs. The three standard data flow schemes used within the EPN are given in Figure 2.

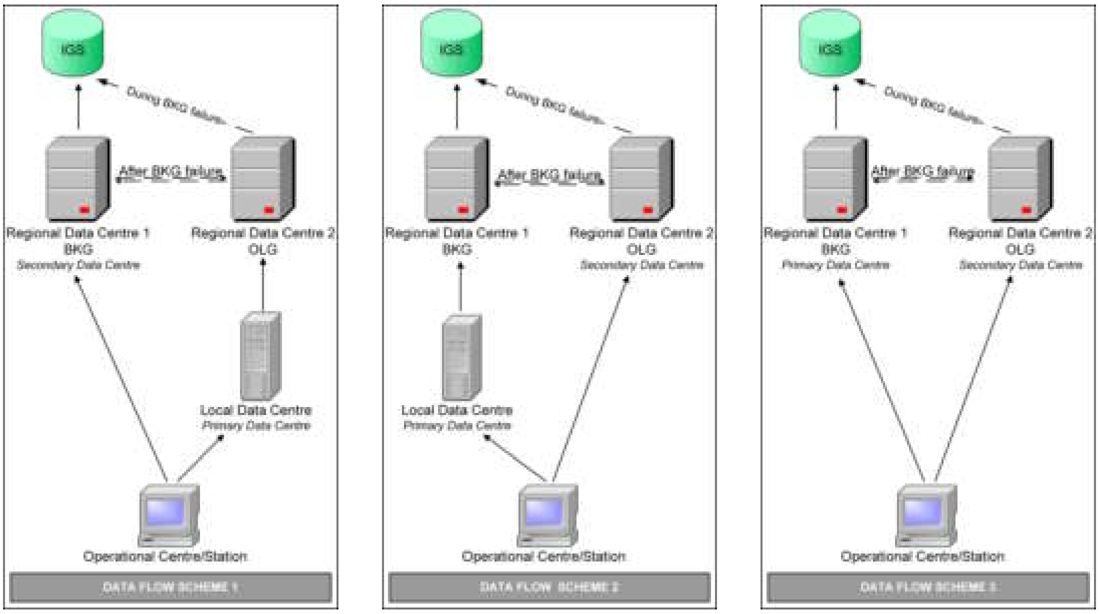

Figure 2 – Recommended EPN data flow (Primary and Secondary data centre as mentioned in site log).

Other data flow related guidelines formalize requirements that were not explicitly mentioned in the previous guidelines but were considered as 'good practices'. Examples are:

- For standard operations, the data delivery to the data centers must be done as quickly as possible which means within 10 minutes after closing time of the file.
- After a communication outage between the station and the OC, or between the OC and the data centers, all recovered data files must be submitted to the data centers.
- If an upload fails, then a retry should be made as quickly as possible. At least a second retry should be done within the hour.
- Hourly files, which could not be sent, or have to be updated, must arrive within three days. After that date, updates must be done through the upload of the appropriate daily file.

New features at EPN CB web

The EPN CB web created new web pages indicating the quality of the EPN data, including

- a yearly plot displaying the tracking performance based on the daily percentage of GPS observations (refreshed daily);

- yearly and 45-day average plots displaying the number of observations and cycle slips, and the RMS due to the multipath on the observed L1 and L2 (refreshed daily);
- monthly snapshots of the satellite tracking (one plot each month).

These pages (http://www.epncb.oma.be/_trackingnetwork/qualityplots/XXXX.html with XXXX= the station 4-char abbreviation) have proven to be a valuable tool to correlate tracking changes with irregularities in the coordinate time series.
Within the EPN, about half the stations deliver hourly data. To encourage these stations to deliver data with a minimal latency, the EPN CB started to monitor the latency of the hourly data in the different EPN data centers. The results of this monitoring have been converted into graphics which can be viewed on-line by using the link "Hourly Data Latency" on the page http://www.epncb.oma.be/_trackingnetwork/info/XXXX.html (with XXXX= the station 4-char abbreviation).
As an example, the results for the period mid-June to mid-September 2004 showed that the number of hourly RINEX files delivered within 10 minutes is 61% in average and the number of missing files is 18% in average. It is clear that although some stations do perform well, a lot of others submit hourly data with unacceptable high latencies. In addition, for several stations, one out of five hourly data file never arrives at a data center. The new EPN data flow guidelines target at improving this situation.

EUREF-IP

In June 2002, EUREF decided to set up and maintain a real-time GNSS infrastructure on the Internet. This real-time GNSS data service "EUREF-IP" uses a new dissemination technique called "Networked Transport of RTCM via Internet Protocol" (Ntrip), which was standardized in September 2004 by the SC 104 of the Radio Technical Commission for Maritime Services (RTCM).

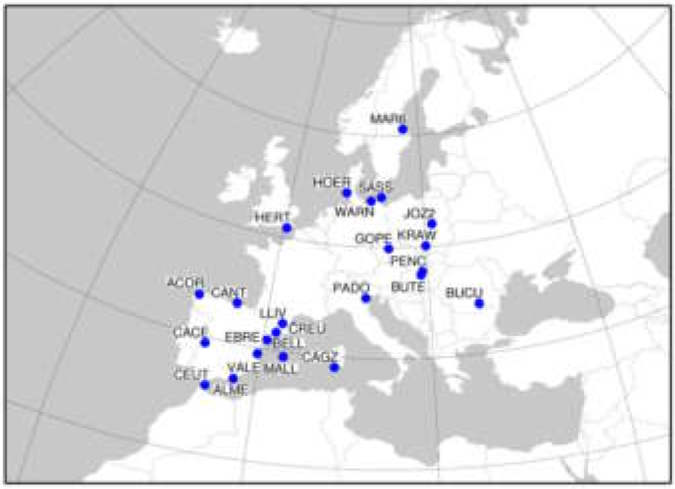

Figure 3 - Map of the EUREF-IP network

Ntrip Client software is now available for various platforms (Windows, Windows CE, Linux, Palm OS) and can be downloaded from http://igs.ifag.de/index_ntrip_down.htm. In addition, a number of commercial products for several mobile phones (Motorola and Symbian OS) is on the market as well. Ntrip Broadcaster software for Linux can be obtained from the same webpage given above. Ntrip Server software (for Windows and Linux) along with additional tools, e.g. to decode RTCM data, is also available.

Currently 24 EPN stations (see Figure 3), providing 32 real-time data streams, are available in different formats, mainly RTCM corrections but also raw receiver data. Users are able to receive the EUREF-IP data streams from 4 Ntrip Broadcasters located in Spain, Italy, Hungary and Germany.
At present, no consistent concept exists for GNSS real-time data dissemination. The coordination of the efforts of EUREF-IP and IGS Real-Time Working Group is in progress and has to be enhanced and enforced.

NtripCaster	**IP-Port**	**Operator**	**Country**
EUREF-IP	www.euref-ip.net:2101	BKG	Germany
Instituto Geografico Nacional	80.38.104.84:2101	IGNE	Spain
Satellite Geodetic Observatory	82.131.181.15:2101	FOMI	Hungary
University of Padova	147.162.229.36:2101	UniPD	Italy

Table 1 - List of the EUREF-IP Broadcasters

EUREF-IP Pilot Project

Denise Dettmering and Georg Weber
Federal Agency of Cartography and Geodesy
Frankfurt, Germany

In June 2002 the IAG Reference Frame Sub-Commission for Europe (EUREF) decided to set up and maintain a real-time GNSS infrastructure on the Internet. This real-time GNSS data service named “EUREF-IP Pilot Project” uses a new data dissemination technique called “Networked Transport of RTCM via Internet Protocol” (Ntrip), which has been standardized in September 2004 by the Special Committee 104 of the Radio Technical Commission for Maritime Services (RTCM SC104).

Currently 32 IGS sites in 14 countries provide real-time data streams within Ntrip. Besides Europe, stations so far are located in Korea, Chile and the USA. Most of them disseminate data in raw receiver format. Some are sending RTCM corrections. Access to data requires a registration. Users may receive the IGS real-time data streams from three Ntrip Broadcasters in the Czech Republic, Italy and Germany.

At present, no consistent technical concept and policy exists for GNSS real-time data dissemination. However, a coordination of efforts within the EUREF-IP Pilot Project and the IGS Real-Time Working Group is in progress."

Korean Regional GPS Network

James Park and Hyung-Chul Lim

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Introduction

Since the late 1990's, five Korean governmental agencies have established a nationwide continuous GPS stations called the Korean GPS Network (KGN). Up to now, the total number of stations of KGN is more than 70 including two IGS stations (DAEJ, SUWN). Most of the stations are operated as geodetic-quality sites, and their data are used for surveying, cartography, atmospheric science and geodynamical studies such as crustal deformation in Korea and plate tectonic motion in and around Korean peninsula. The geographical distribution of Korean continuous GPS stations is shown in Figure 1.

Korean GPS Network

In Korea, the first continuous GPS station for precise surveying was established by Korea Astronomy and Space Science Institute (KASI) in 1994. With the increasing requirement, a number of continuous GPS stations in Korea were established gradually in years 1999 and 2000. At the end of 2004, more than 70 continuous GPS stations were distributed throughout the country by five Korean governmental agencies. Thus the KGN can be used or tested for special researches such as local troposphere monitoring because the distances among the stations range from 30 km to 50 km. As Figure 1 shows, KASI has operated 9 stations including an IGS station (DAEJ), Ministry of Government and Home Affairs (MOGAHA) has 30 stations, Ministry of Maritime Affairs and Fisheries (MOMAF) has 16 stations with future plan of 25 stations, National Geographic Information Institute (NGII) has 14 stations including an IGS station (SUWN), and Korea Institute of Geoscience and Mineral Resources (KIGAM) has 4 stations. All stations are equipped with the dual frequency receiver and measurement data of GPS stations can be downloaded through the internet or public telephone lines from the data centers in each agency.

The characteristics of KGN are summarized in Table 1.

Data Service of KGN

The data center of each agency downloads 24 hour measurement data in its own stations once per a day, and reserves all. Even though RAW and RINEX data is preserved in the data center of each agency, KASI data center stores RINEX data of MOGAHA, NGII and KIGAM a few months later for the purpose of backup but RAW and RINEX data of KASI and MOMAF can be acquired in near real time. DAT and RINEX data of KASI, MOMAF and NGII are available in their homepages of Korean version through the internet access. In near future, RINEX data of KGN will be supplied to the worldwide users through the internet access to KASI data center.

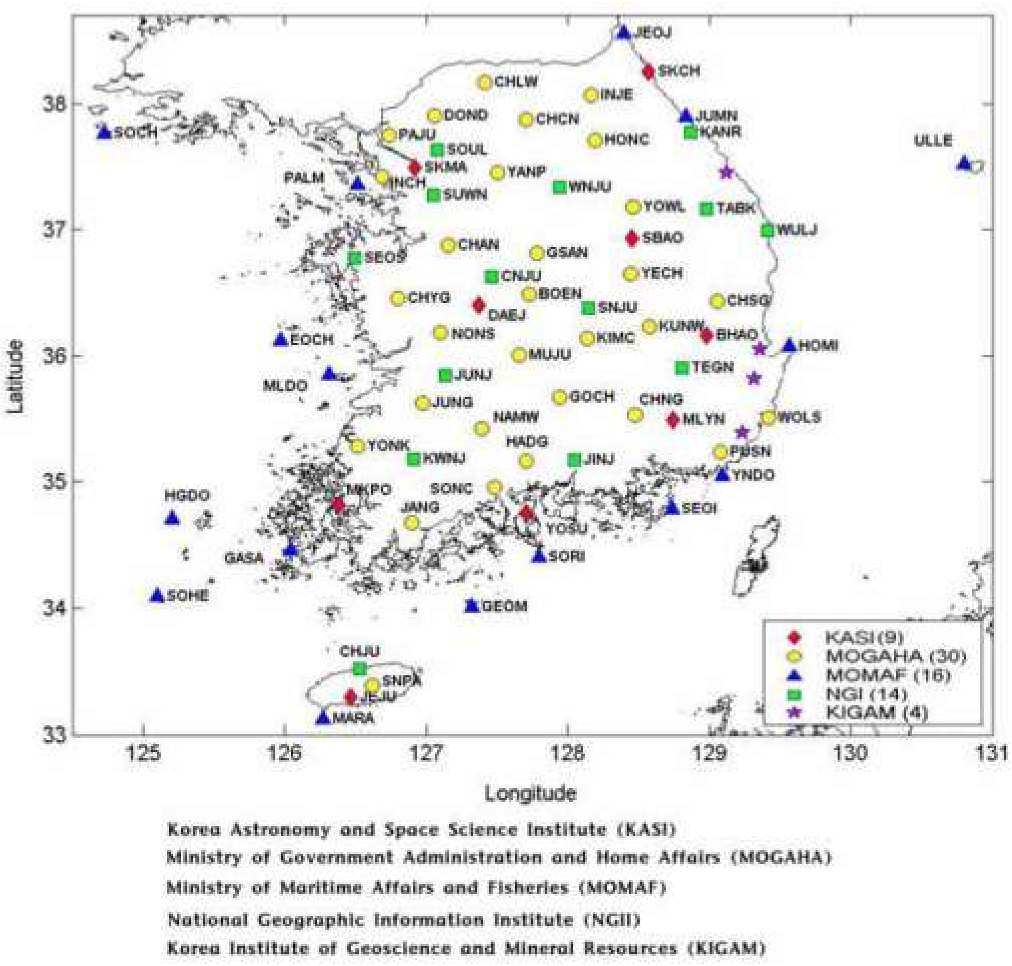

Figure 1. Korean continuous GPS stations

Table 1. The Characteristics of KGN

Agency	KASI	MOGAHA	MOMAF	NGII	KIGAM
Mission	Science and Applications	Surveying	Marine Navigation	Map/GIS	Crustal Movement
Sites	9	30	16	14	4
Receiver	Trimble 4000SSI NetRS	Trimble 4000SSI	Trimble 4000RS/IM	Trimble 4000SSI	Trimble 4000SSI/SSE
Antenna	Choke-Ring	L1/L2 GP	L1/L2 GP	Choke-Ring	Choke-Ring L1/L2 GP
Comm. Link	Internet PSTN	PSTN	PSTN Dedicated Line	PSTN	Internet PSTN

IGS Stations (DAEJ and SUWN)

TAEJ was the first IGS station in Korea, which was officially joined to IGS in 1995 and moved to DAEJ in 1999. DAEJ has been operated by KASI and is equipped with Trimble NetRS GPS receiver, choke-ring antenna, MET sensor and cesium atomic clock. DAEJ GPS receiver was changed from 4000SSI to NetRS at the beginning of 2005. SUWN has been operated by NGII from 1997 as an IGS station, which is equipped with Trimble 4000SSI GPS receiver, choke-ring antenna and cesium atomic clock. SUWN GPS receiver was changed from Turbo ROGUE SNR-8000 to Trimble 4000SSIetRS at the beginning of 2000. In the near future, MOMAF will establish an additional IGS station which will locate in the neighborhood of the East Sea.

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The Australian Regional GPS Network (ARGN)
Report for 2003 & 2004

R. Twilley
Geoscience Australia

Introduction

The Australian Regional GPS Network (ARGN) continued a period of consolidation during 2003/04, following the 1st year of integration between AUSLIG and the Australian Geological Survey Organisation (AGSO) to form Geoscience Australia (GA). The network continued to operate at a very high level with data quality, completeness and latency being the main areas of improvement. One new station was added to the ARGN and also included into the IGS during 2003/04 , the Sydney station SYDN. The importance of this was due to the fact that it is located and collocated, at Australia's National Time Agency, the National Measurement Institute (NMI).
The Networks communications was enhanced with the implementation of a number of VSAT communication dishes at key sites. Also during the year there were a number of stations upgraded to include the capture of meteorological data and timing improvements with the addition of GPS steered Rubidium (Rb) time frequency standards.

Performance

The ARGN continued to operate at a high level of performance throughout 2003 and 2004, as evidenced by the performance graphs available on the Geoscience Australia web site (www.ga.gov.au/nmd/geodesy/argn/argnqual.htm) and confirmed by benchmarking with IGS.

Improvements

The ongoing program of receiver replacement upgrades continued through 2003/04, to provide more reliability and functionality. The more modern replacement receivers allow more efficient operation by being able to provide high rate data, consuming less power and providing better remote access.

Near Real Time (NRT) data (Hourly) is now available from all ARGN stations and development is underway to provide Real Time, High Rate (1Hz) data in the RTIGS format from a number of IGS stations within the network next year.

A regular schedule of site visits continues, including the continued monitoring of monument stability by accurate local surveys to nearby stable reference marks. No apparent movement was found during these surveys.

During 2003/04 Geoscience Australia personnel continued to participate in a joint project with Natural Resources Canada (NRC) to test and enhance the capabilities to provide RTIGS data.

Conclusion

The ARGN continues to provide quality GPS data from a wide geographical region, from the Australian tropics to Antarctica. Despite the challenges of remote localities, unmanned sites and harsh environments, the sites are remarkably robust and reliable. To further enhance this, the equipment, communications and associated software continue to be improved.

The ESA/ESOC IGS Station Network
Annual Report 2003-2004

J.M. Dow, C. García[‡], J. Feltens[†], T. Springer[‡], J. Perez[‡], H. Boomkamp[‡], E. Rojo[‡], I. Romero[‡]

ESA/European Space Operations Centre,
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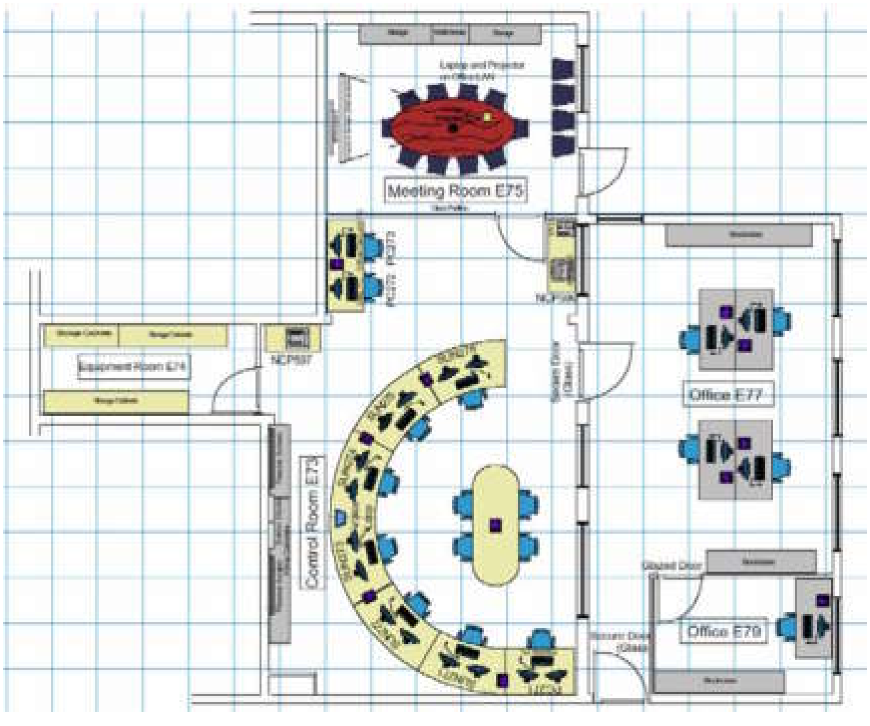
[†] EDS at ESA/ESOC
[‡] GMV at ESA/ESOC

Introduction

This Report gives an overview of the ESOC GPS station network activities during the period 2003-2004.

In addition to enhancing the network with an additional station at Redu (Belgium) the main activities have been concentrated in the production of a stable stream of 1 Hz real time data from the stations to the control centre at ESOC. Cooperation within the IGS Real Time Working Group for the sharing of the data streams from the stations has been initiated and the first streams delivered.

A new Navigation Facility was created at ESOC in 2004 to provide the proper hosting for all the necessary infrastructure to operate the network in a reliable way.

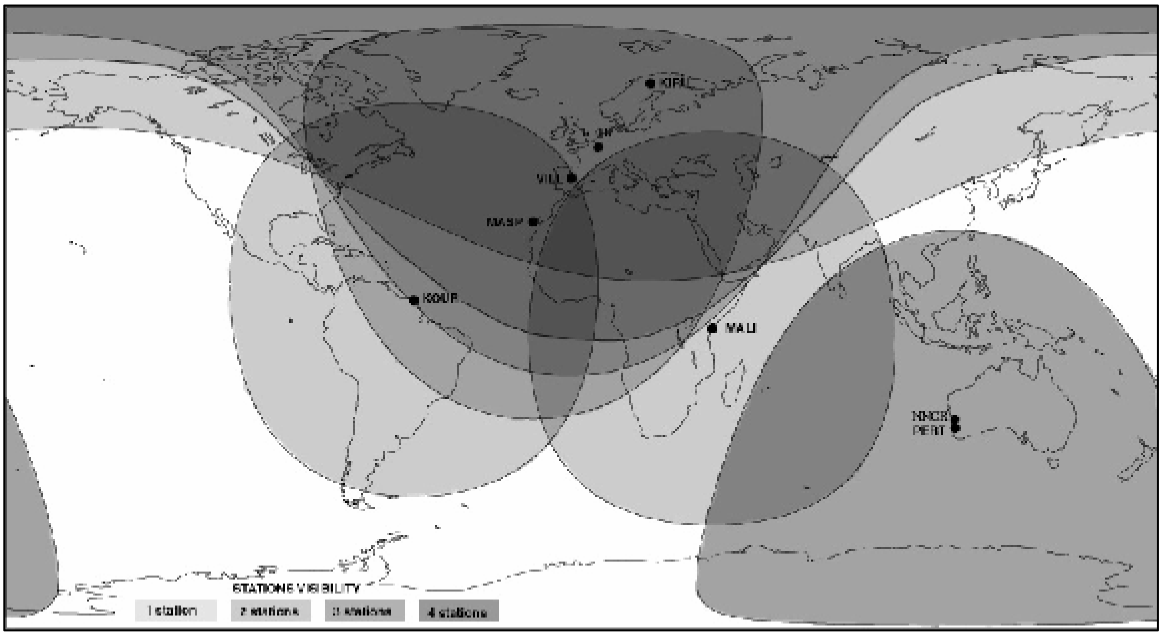


THE ESA/ESOC NAVIGATION FACILITY

The figure below shows the visibility of the ESA/ESOC network with 20 degree minimum elevation.

ESA Stations' Distribution

and Visibility (20° min. elev.)



ESA/ESOC NETWORK VISIBILITY

Changes and activities in 2003-2004

The station upgrades have been correspondingly reflected in the IGS Station Information Logs to inform the IGS community. They are mainly:

Kiruna: The receiver was exchanged in March 2003. A dome was also installed at the same time in order to improve the height estimates of the station due to problems with discontinuities around the frost and non-frost seasons. Since March 2004 the station is delivering data in real time through the IGSRTWG.

Kourou: There are two receivers running in parallel at Kourou. The GPS receiver worked without anomalies during 2003 and 2004. The GPS+GLONASS station restarted operation in September 2003 after several months of downtime needed for the repair of the antenna.

Malindi: Since December 2004 a new permanent link is making the communication to the station very reliable. To improve the masking of the antenna, the surrounding palm trees have been trimmed at the end of 2004.

Maspalomas: Starting in March 2004, it contributes real time 1 Hz data to the IGSRTWG.

New Norcia: The operation has been smooth since the installation in June 2002. There are plans to improve the signal from the Hydrogen Maser that is located very distant from the receiver.

Perth: Receiver and antenna were exchanged in June 2003 after the problems caused by a lightning strike.

Redu: The station was created in April 2003 and is since then delivering data in a reliable way.

Villafranca: We only have to report the failure of the receiver in December 2004 that was immediately changed by the on-site spare unit.

	KIRU	KOUR	MALI	MAS1	NNOR	PERT	VILL	REDU
Receiver	microZ	Z-XII	Z-XII	Z-XII	Z-XII	microZ	Z-XII	microZ
On-site back-up equipmnt	Turborogue ACT	iCGRS + antenna	microZ + antenna	Turborogue ACT +antenna	microZ + antenna			
Computer	2 units	2 units	2 units	2 units	2 units	2 units	2 units	1 unit
Oscillator	Cs	Cs	Rb	Cs	H-Maser	Cs	Cs	Cs
Comms	Internet	Intranet (Office LAN)	Intranet (Opsnet)	Internet	Intranet (Opsnet)	Intranet (opsnet)	Intranet (Office LAN)	Intranet (Office LAN)
Real time status	1 Hz to ESOC and IGS	1 Hz to ESOC	1 Hz to ESOC	1 Hz to ESOC and IGS	1 Hz to ESOC	1 Hz to ESOC	1 Hz to ESOC	

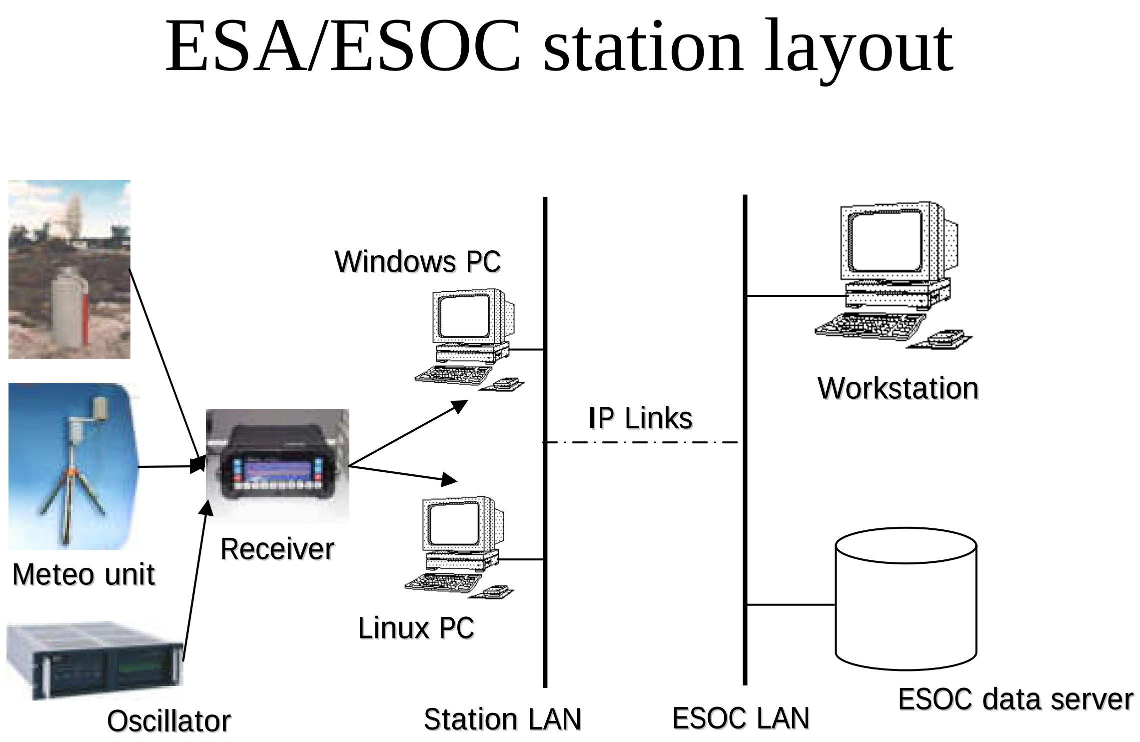
ESA/ESOC GPS NETWORK STATUS BY THE END OF 2004

A general overhaul is being carried out station by station to have a common set-up and documentation. The GPS installations have been better integrated and documented together with the rest of the ESA stations infrastructure. The picture below shows the general station layout.

The receivers form currently a homogeneous Ashtech network (Z-XII, microZ or iCGRS) with on-site back-up units in nearly all the stations.

All the station have external atomic (Cs) oscillators. At NNOR there is a redundant H maser and Malindi is equipped with a Rubidium.

At every site there are two computers connected to the same station LAN and to one serial port of the receiver.



TYPICAL ESA/ESOC STATION LAYOUT

Real time high rate data network

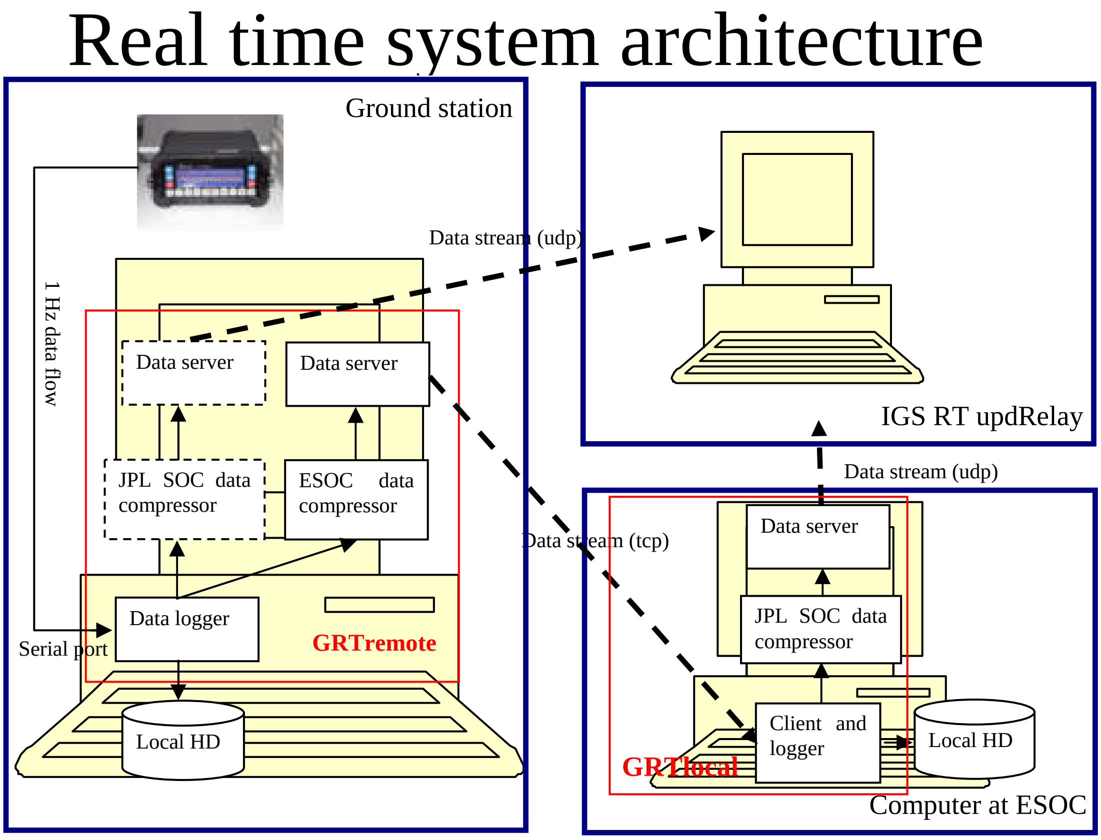
A special emphasis has been performed during 2003 and 2004 to develop a real time high rate data network. The main motivation is, in addition to get and use the streams in real time, to reduce the latency of the currently very demanded near real time 15 minutes files.

It is based on the ESA Ground Stations infrastructure and the recent development of IP communications in the last years.

The real time data transmission system is called GRT (GNSS Real Time System). It is made up of:

- GRTremote for remote stations:
  - Data reading from the receiver serial port.
  - Compression.
  - Sending to the network sockets and to the local disk.
- GRTlocal at ESOC:
  - Data reception from the network.
  - Uncompression.
  - Splitting into files in the local disk.

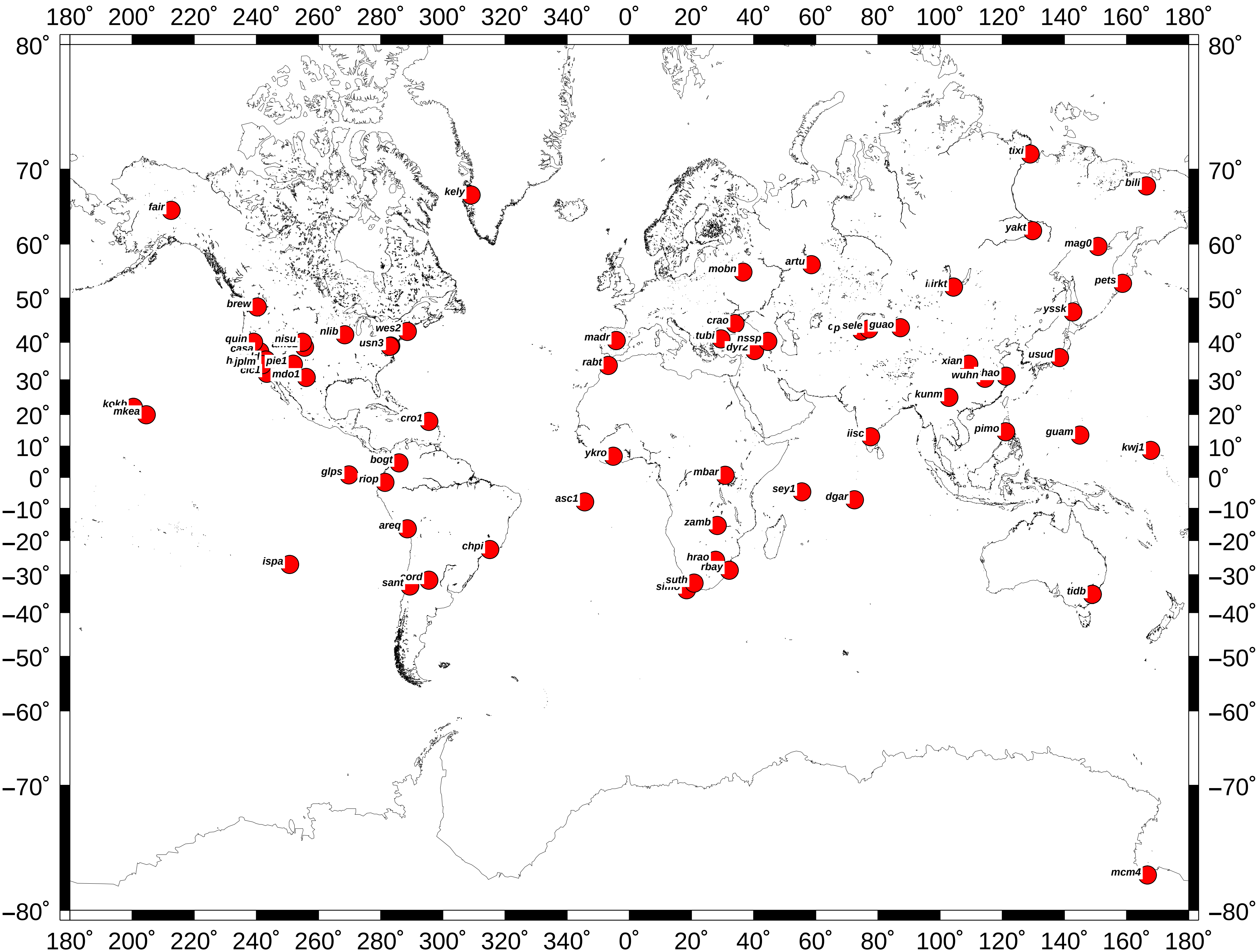
Several experiments were carried out to integrate the real time network in the IGS prototype. The figure below depicts the architecture developed to deliver the data to ESOC and also to the IGS relay servers. Data from Maspalomas and Kiruna are being routinely delivered to the IGS. The other stations will follow when a better integration is achieved as it is planned for 2005.



Web pages

Updated information and pictures from the stations are available from the ESOC Navigation web:

http://nng.esoc.esa.de



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NASA Cooperating sites within the IGS

Status of the IGS Stations Provided by the Main Astronomical Observatory in 2002—2004

O. Khoda

Main Astronomical Observatory of the National Academy of Sciences of Ukraine, Kiev, Ukraine

At the end of 2004 Main Astronomical Observatory of the National Academy of Sciences of Ukraine (MAO) operates four permanent GPS stations: Kiev/Golosiiv (GLSV), Uzhgorod (UZHL), Kharkiv (KHAR), and Evpatoria (EVPA) (Fig. 1).

GLSV and UZHL are IGS stations since May 6, 1998 and July 27, 1999 respectively. KHAR station was installed in November 23, 2002 in National Scientific Centre “Institute of Metrology” in city of Kharkiv. It works with external 5 MHz frequency standard (H–maser). EVPA station was installed in November 26, 2002. It is situated at National Centre of Space Devices Control and Test of National Space Agency of Ukraine, approximately 14 km from city of Evpatoria, and collocated with SLR station (1867 Evpatoria) and 70–m radiotelescope. In 2004 KHAR and EVPA were included in EPN list of proposed stations.

All stations are equipped with *Trimble 4000SSi* receivers and choke ring antennae (TRM29659.00), track all GPS satellites above 5 deg, and store all observables with recording interval 30 seconds. Stations GLSV and KHAR produce hourly data files (GLSV since

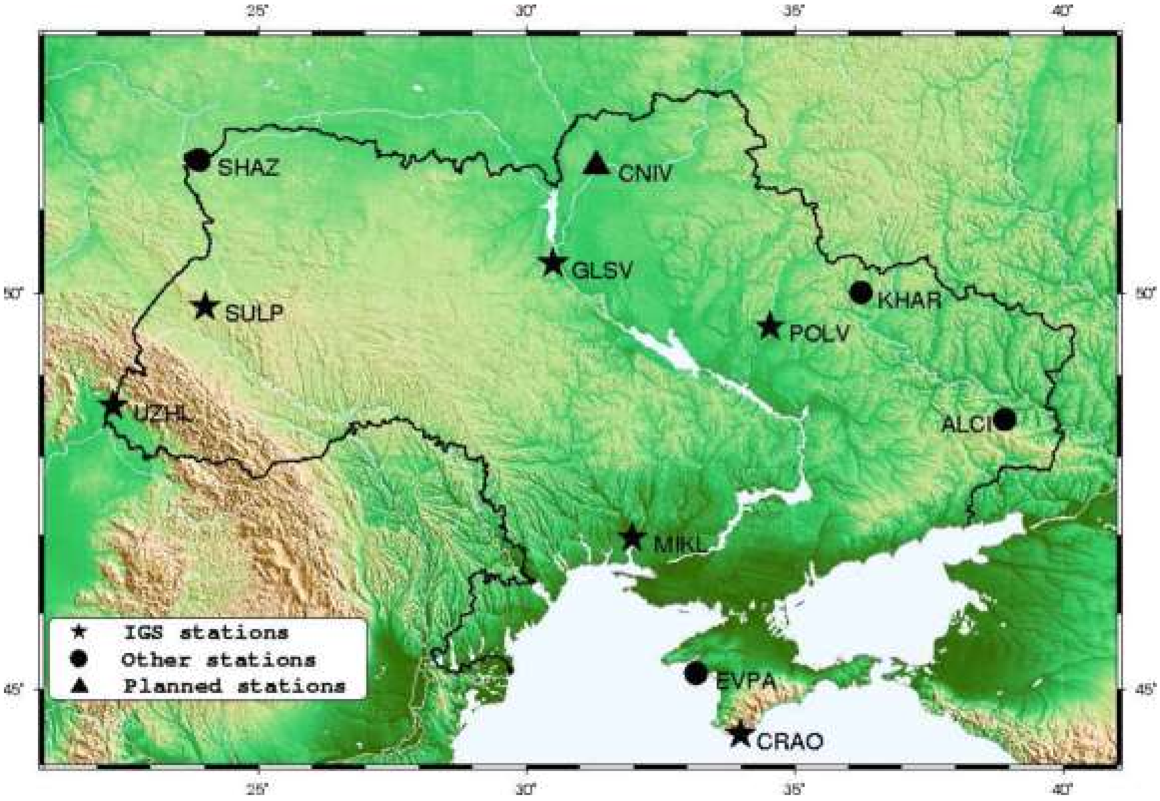

Figure 1. Ukrainian Permanent GPS Network (end of 2004)

December 8, 2003, KHAR since December 12, 2003). On–site computers at all stations use Linux operational system and managing software *ggps* (the Bourne–Again shell script developed by MAO that uses *R-utilities*, *teqc*, *RNX2CRX*, and *CRX2RNX*, freely distributed in Internet). Stations work in full automatic mode. Raw data files are sent to the Operational Center (OC) at MAO, where data are translated to the Compact RINEX format. Then, if needed, data are sent to the IGS Regional Data Centre in BKG (Frankfurt–am–Main, Germany) and EPN Regional Data Centre in Space Research Institute of the Austrian Academy of Sciences (Graz, Austria).

MAO OC also operates Ukrainian IGS stations Poltava (POLV) and Mykolaiv (MIKL, installed in April 20, 2002), and new station Alchevsk (ALCI, installed in November 29, 2003).

MAO created the Local Data Centre where all data from all Ukrainian permanent GPS stations are stored. Observation data for last year are available at Observatory's ftp server (ftp://ftp.mao.kiev.ua/pub/gps/data/daily/). The earlier data can be obtained on request.

In summer of 2005 MAO in cooperation with Chernihiv State Institute of Economics and Management is planning to install new permanent GPS station in city of Chernihiv.

SVTL IGS Station Report 2003–2004

Iskander Gayazov, Zinovy Malkin, Vladimir Sharkov
Institute of Applied Astronomy RAS, St. Petersburg, Russia

Permanent GPS station SVTL is installed in 1996 at the Svetloe Radio Astronomical Observatory (SvRAO) located at the Karelian Neck in about 100 km towards North from St. Petersburg, and is operated by the Institute of Applied Astronomy of the Russian Academy of Sciences. The station is continuously operated since March 1996. In 1996 SVTL station was included in the EUREF/EPN network, and in December 2003 it has been added to the IGS network. GPS antenna is installed on concrete pillar on the flat roof of the 2-story laboratory building. It is collocated with IVS station SVETLOE.

Till December 2004 the station was equipped with Trimble 4000SST receiver and TRM14532.00 antenna provided by UNAVCO (Fig. 1). On December 1, 2004 it was replaced with Leica SR520 receiver and LEIAT504 antenna with LEIS radome (Fig. 2). Table 1 shows significant improvement in data quality after the change of equipment.

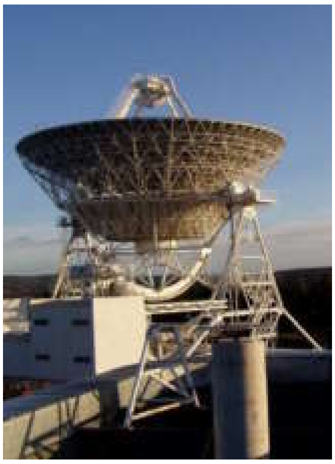

Figure 1. Trimble antenna and VLBI telescope.

Figure 2. Leica antenna.

Table 1. Comparison of Trimble and Leica receivers (IGS data used for the first four lines).

Value	Trimble 4000SST, November 2004	Leica SR520, December 2004
Daily number of observations	22500	26000
Data collection percentage	86	99
Multipath, m	3	0.2
Cycle slips / 1000 observations	15	4
Uncertainty of weekly station coordinates, mm, X/Y/Z	3.3/2.3/6.2	2.2/1.4/4.1

In November–December 2004 we performed parallel observations with old (Trimble) and new (Leica) receivers/antennas installed on two adjacent marks spaced by about 2 m. During the first 20 days the Trimble antenna was installed on the mark 101 (SVTL), and the Leica antenna was installed on the mark 113. Then the antennas were transposed for the next 19 days. Processing of the observations showed the systematic difference between coordinates obtained with two receivers of about 8 mm in U and N directions, and about 2 mm in E direction.

IGS Clock Products Working Group

Ken Senior
U.S. Naval Research Lab (NRL)

1 Use of IGS Products in TAI

Established by the Convention of the Metre in 1875, the Bureau des Poids et Mesures (BIPM) provides the basis for and coordination of a coherent system of measurements throughout the world, traceable to the International System of Units (SI). Since 1988, these activities include the definition and realization of the world's timescales, International Atomic Time (TAI) and Coordinated Universal Time (UTC), as well as the SI second. In order to facilitate the derivation of these timescales, clocks located at timing laboratories throughout the world are intercompared, primarily utilizing Global Navigation Satellite Systems (GNSS) such as GPS. In order to facilitate this, the BIPM has historically used IGS products including GPS ephemerides, as well as global ionosphere maps. In 2004/2005 the BIPM reviewed a new "GPS all-in-view" technique for such comparisons. This new technique utilizes IGS satellite clock estimates and IGS timescales resulting in reduced noise compared with traditional common view methods. With the proliferation of IGS sites collocated at timing laboratories (see Table 1), the direct use of IGS station clock estimates to link timing laboratories is also being considered. Proposals to consider operational implementation of these are expected at the next meeting in September 2006 of the Consultative Committee for Time and Frequency (CCTF), the governing body of the BIPM for matters of time and frequency. The IGS has been asked to report on the metrology of IGS products as well as its commitment to continue providing them. This report will be delivered by Ken Senior (NRL) as the current IGS representative to the CCTF.

2 IGS Timescales Status

Figure 1 shows the performance of the IGS timescales from their inception. NRL generates two timescales, IGST and IGRT—one for each of the Final and Rapid combined clock product series. The purpose of these timescales is to provide robust and stable references for its GPS tracking station and satellite clock products chiefly for the purpose of monitoring station and satellite clock performance. Because the IGS timescales are also aligned approximately to GPS Time (offset from UTC by an integer number of seconds), the combined GPS orbit and clock estimates may be used in Precise Point Positioning (PPP) mode both to autonomously position isolated GPS receivers at the few-centimeter level as well as to disseminate UTC at comparable levels (modulo 1 second). For the highest accuracy results, instrumental calibration of the internal delays within the user receiver equipment is also required. Though the 1-day instabilities of IGRT and IGST are about 10^{-15}, continued medium- and long-term instabilities dominate both scales. These are attributable largely to the UTC alignment procedure, which is currently achieved by steering the timescales to GPS Time. Additional limitations include overly conservative weighting of the included frequency standards.

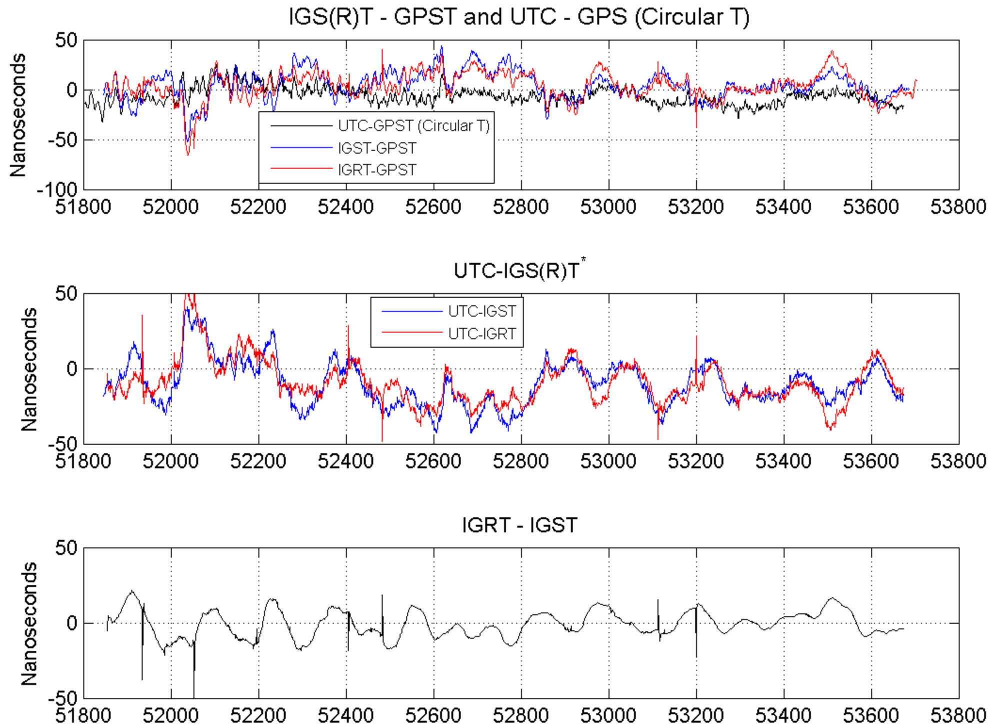

Figure 1. IGS Timescales measured against GPS Time and UTC. The large spikes in the middle and bottom panels are known errors in the Rapid alignment of IGS products to GPS Time prior to realignment to IGRT. They are not attributable to the IGS timescales.

3 Planned Improvements for 2006

- Currently, the IGS timescales are dominated by the H-Masers in the IGS tracking network. A new timescale algorithm currently under development at NRL will make better use of the Cesium clocks as well as the H-Masers, taking advantage of their greater long-term stability.
- The number of IGS stations collocated at BIPM time laboratories continues to grow, the current list being shown in the table below. With each laboratory generally providing local realizations, UTC(k), of UTC via local timekeeping and time dissemination systems, one obvious improvement to the alignment of the IGS timescales to UTC would likely come from utilizing this network of UTC(k) realizations. However, only a few of these colocated stations have been absolutely calibrated. In [Senior et al., 2004] the authors demonstrated a new *in situ* technique for calibrating a subset of these stations. Using this new calibration technique, we anticipate using a weighted ensemble of these UTC(k) realizations in addition to GPS Time as a long-term steering reference for the IGS timescales.

Table 1 IGS Stations Colocated at BIPM Time Laboratories

IGS Site	Time Lab	GPS Receiver	Freq. Std.	Location
AMC2	AMC *	Ashtech Z-XII3T	H-Maser	Colorado Springs, CO
BOR1	AOS	AOA TurboRogue	Cesium	Borowiec, Poland
BRUS	ORB	Ashtech Z-XII3T	H-Maser	Brussels, Belgium
IENG	IEN *	Ashtech Z-XII3T	Cesium	Torino, Italy
KGN0	CRL *	Ashtech Z-XII3T	Cesium	Koganei, Japan
MDVJ	VNIIM	JPS Legacy	H-Maser	Mendeleevo, Russia
MIZU	NAO	AOA Benchmark	Cesium	Mizusawa, Japan
NISU	NIST *	Novatel	H-Maser	Boulder, CO USA
NPLD	NPL *	Ashtech Z-XII3T	H-Maser	Teddington, UK
NRC1	NRC *	AOA SNR-12	H-Maser	Ottawa, Canada
NRC2	NRC *	AOA SNR-8100	H-Maser	Ottawa, Canada
OBE2	DLR	AOA SNR-8000	Rubidium	Oberpfaffenhofen,
OPMT	OP *	Ashtech Z-XII3T	H-Maser	Paris, France
PENC	SGO	Trimble	Rubidium	Penc, Hungary
PTBB	PTB *	Ashtech Z-XII3T	H-Maser	Braunschweig, Germany
SFER	ROA *	Trimble 4000SSI	Cesium	San Fernando, Spain
SPT0	SP *	JPS Legacy	Cesium	Boras, Sweden
SYDN	NMI	JPS E_GGD	Cesium	Sydney, Australia
TLSE	CNES	AOA TurboRogue	Cesium	Toulouse, France
TWTF	TL *	Ashtech Z-XII3T	Cesium	Taoyuan, Taiwan
USNO	USNO *	Ashtech Z-XII3T	H-Maser	Washington, DC USA
USN3	USNO *	Ashtech Z-XII3T	H-Maser	Washington, DC USA
WAB2	CH *	Ashtech Z-XII3T	H-Maser	Bern, Switzerland
WTZA	IFAG	Ashtech Z-XII3T	H-Maser	Wettzell, Germany
WTZR	IFAG	JPS E_GGD	H-Maser	Wettzell, Germany

* *participates in two-way satellite time transfer (TWSTT)*

- The new weighting algorithm will be less conservative than the current one, which often unnecessarily penalizes good frequency standards.
- Better determination of process noise parameters. The current IGS timescale filter is not optimally tuned. This has not hitherto been an issue given the penalty suffered by steering to GPS Time.

4 *New* Station Performance Statistic

With regard to timing, geodetic analysis of the GPS code/pseudorange ($\sigma \sim 1$ meter) and phase ($\sigma \sim 1$ centimeter) observables yields a unique characteristic in the resulting clock estimates which is often misunderstood or mischaracterized. All relevant geodetic quantities of interest, including position and tropospheric delay, are determined from the significantly more precise phase data—except for the clock estimates. Within a processing arc, typically 1 day, the variations of the clock estimates are determined by the phase data. However, owing to the unknown phase ambiguities, no absolute time may be determined from the phase data alone. Thus, the overall time bias of the arc is determined from the noisier code data. The result is small discontinuities at the processing arc boundaries, which reflect the inherent accuracy of the integrated code data over the respective arcs. Figure 2 shows the IGS Final combined clock estimates for nine stations which are driven externally by H-Masers during the period 5–15 February 2002. The estimates—each referenced to the IGS Final timescale IGST—are tabulated at five-minute intervals and are reduced in one-day arcs. As the figure shows, the magnitude of the discontinuities varies greatly among the sites.

By utilizing the large IGS network and by using the IGS timescales as a reference, the authors in [Ray & Senior, 2003] showed that the day-boundary discontinuities are mean-zero, Gaussian, but have variances which are highly site-dependent. The RMS of the clock discontinuities ranges from about 120 ps for the best sites to more than 1 ns for others. The discontinuities may partially be explained by thermal effects in some cases and equipment problems in others. However, remaining discontinuities are likely caused by code multipath though this has not been independently demonstrated.

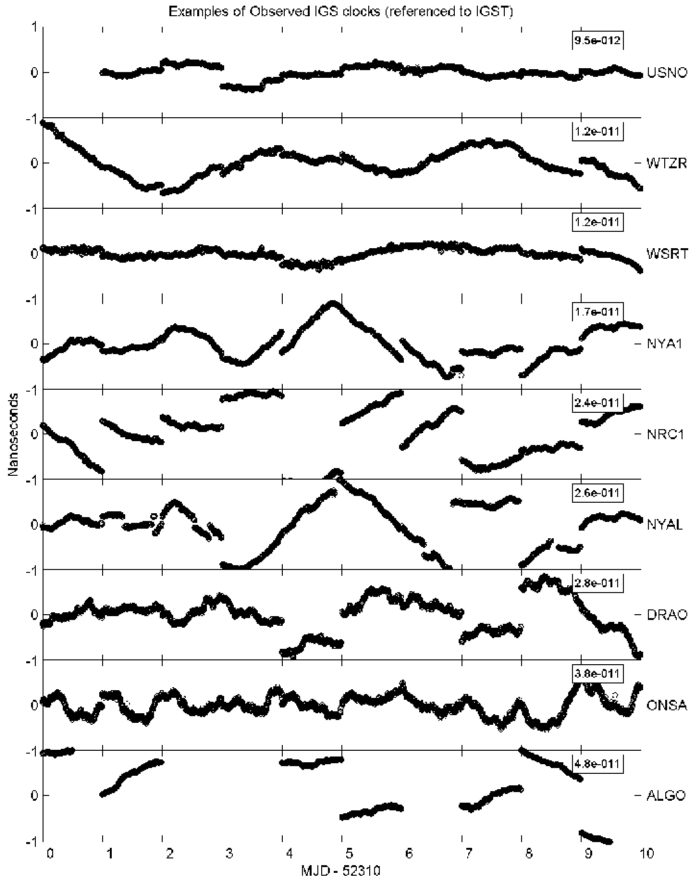

Figure 2 IGS Final clock estimates for nine stations driven externally by H-Masers for the ten-day period 5–15 February 2002. Each station has been referenced to the IGS Final timescale IGST and a separate quadratic has been removed from each. The boxed value shows the Allan Deviation at 300 s. The plot demonstrates that the magnitude of the day-boundary discontinuities varies greatly among the stations and does not correlate with local clock instability.

Figure 3 shows the day-boundary discontinuities for the site ALGO at Algonquin Park, Ontario, Canada where a noticeable increase in the RMS of the discontinuities is evident during the winter months. Table 2 summarizes RMS values of the day-boundary discontinuities for all IGS sites contained in the IGS combined clock products and which are driven externally by H-Masers. As the table shows, the variance of the discontinuities for each site ranges in magnitude from ~120 ps to over a nanosecond for some sites. In an attempt to remove such discontinuities, many have suggested alternative solutions which usually amount to nothing more than smoothing of the estimates. However, as outlined below, the discontinuities offer an invaluable tool in gauging the true timing uncertainty of the geodetic estimates as well as in monitoring the timing performance of geodetic stations—information which can only be lost when the independence between processing arcs is sacrificed to smoothing.

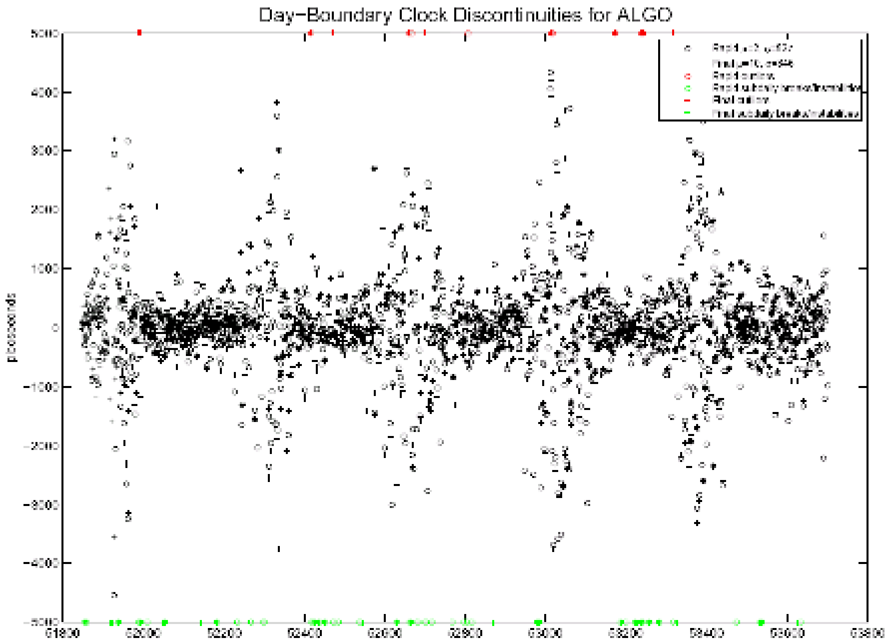

Figure 3 Day-boundary discontinuities for the Rapid and Final IGS clock estimates for the site ALGO at Algonquin Park, Ontario Canada for a period of several years. Each point in the plot shows the discontinuity of the geodetic estimates across the day boundary. A discrete seasonal increase in the RMS of the discontinuities during winter months is notable and is only partially explained by thermal effects. A likely candidate for the discontinuities is code multipath.

Table 2 RMS of Day-Boundary Discontinuities for IGS sites driven by H-Masers.

IGS Site	Rapid RMS	Final RMS	Remarks as of 15 November 2005
BRFT	123	98	new station; very sparse data
ONSA	143	117	best long-term performance
AMC2 *	288	120	improved after changes on 2002-7-3
USUD	189	137	clock has high short-term noise
OBET *	--	146	very sparse data
BRUS *	147	149	improved after summer 2003
TWTF *	159	150	
PTBB *	150	--	sparse data
OS0G *	179	156	station discontinued
MAD2	253	163	
GODZ	181	167	sparse data
BREW	202	192	
USN1 *	231	194	station discontinued
GODE	178	195	
USN3 *	204	211	improved after Jan. 2005
CRO1	257	216	clock has high short-term noise
WTZR	183	216	clock shows signal interference
YEBE	243	221	
NPLD *	270	247	
KHAJ	--	260	
WSRT	247	263	
MATE	316	281	improved after summer 2003
NOT1	303	302	
CHUR	287	306	
IRKT	394	313	
NLIB	376	328	
KOKB	330	337	improved after ant change May 2004

OPMT *	385	338	
USNO *	356	343	
ALBH	530	345	greatly improved after Sept. 2003
TIDB	374	346	degraded after Jan. 2005
NYAL	388	359	
STJ0	361	360	
PRDS	366	367	sparse data
WES2	291	375	
FAIR	429	445	improved after ant changes Dec. 2004
PIE1	444	473	degraded in late 2004 – early 2005
DRAO	515	499	
FORT	516	501	
NISU *	316	514	little Rapid data
TID1	528	--	degraded after Jan. 2005
MEDI	670	536	
SPT0 *	503	545	mostly degraded since summer 2005
HOB2	576	610	
NYA1	711	614	very degraded in spring 2004
YELL	612	645	large seasonal variations
NRC1 *	731	716	large seasonal variations
ALGO	826	849	large seasonal variations
NRC2 *	960	973	large seasonal variations
MDVJ	--	1531	severely degraded after Oct. 2004
METS	1467	1649	very sparse data

* IGS stations collocated at BIPM timing laboratories

5 *New* Open Source Clock Analysis Package with IGS Clock Products

The source code and executables for a new clock analysis package called CANVAS (the Clock Analysis, Visualization, and Archiving System) were released by NRL in 2005. This package includes an optionally installed database of IGS Rapid and Final Combined Clock Products. Details on obtaining this package may be found in [Senior et al., 2005].

6 IGS Reprocessing

Using the latest in GPS modelling and geodetic techniques the IGS is planning to reprocess historical GPS data back to the beginning of 1994. As part of this effort NGA has provided 4 years of tracking data from its network which will be included in the reprocessing. Current processing time in the IGS timescale algorithm must be improved to make feasible the realignment of reprocessed clock estimates to a stable timescale. Currently, processing takes ~5–7 minutes including generation of plots. The largest bottleneck is the inversion of an $N \times N$ matrix ($N =$ number of clocks). This was originally implemented to allow for the accounting of measurement correlations among various subsets of clocks which is unnecessary for current timescale operation. The new version of the algorithm will improve processing speed considerably.

Issues:

Primary issue will be composition of station clocks in reprocessed combination. Some options which will lighten the burden of ACs:

- Subset of station clocks based on timing importance (H-MASER, CESIUM, Time Lab)
- PPP by ACs submitted to combination
- PPP by ACC/CPWG using combination orbits + sat. clocks

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IGS Ionosphere WG Technical Report 2003-2004

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1. Abstract

This report is focused on summarizing the main activities of the IGS Ionosphere Working Group (Iono-WG) during the years 2003 and 2004. Firstly the consolidation of the IGS Global Total Electron Content maps (IGTEC) as a final Ionosphere IGS product will be shown. And secondly the performance of the rapid IGTECs, which generation was started in December 2003, will be discussed. Another recent activities of the Iono-WG, such as the IGTEC validations with ENVISAT TEC, among the future goals and corresponding tasks will be also summarized.

2. Introduction

The IGS Ionosphere Working Group (Iono-WG) was established by the IGS Governing Board on 28 May 1998 and commenced working in June 1998. The working group's main activity is at the moment the routine provision of IGS Global Total Electron Content (IGTEC) maps with a 2-hours time resolution and of daily sets of GPS satellite and receiver hardware differential code bias (DCB) values. The computation of these TEC maps and DCB sets is based on the routine evaluation of GPS dual-frequency tracking data recorded with the global IGS tracking network.

Initially five IGS Ionosphere Associate Analysis Centers (IAACs) contributed with their ionosphere products to the Iono-WG activities (CODE, ESA, JPL, NRCan, and UPC, see correspondingly details of their techniques in Schaer 1999, Feltens 1998, Mannucci et al. 1998, Gao et al. 1994, Hernández-Pajares et al. 1999). Moreover there were four validation centers: ESA and JPL providing IGS TEC comparison with ENVISAT and JASON altimeters TEC, NRCan and UPC providing weights in function of the IAAC maps quality reproducing GPS observations. Routinely the final IGS TEC maps are computed and distributed from the combination center (firstly ESA and afterwards UPC since end 2002). Indeed, once per week these ionosphere products are compared with a dedicated comparison algorithm. This comparison/combination algorithm was worked out and coded in 1998 from scratch. In the meantime the original comparison/combination algorithm was upgraded with new weights computed from the results of external self-consistency validations (see Feltens 2002). The weekly comparisons are done with this new approach since August 2001. Furthermore, the IAACs TEC maps are routinely validated with TOPEX altimeter data since July 2001, with JASON data since mid. 2003 (see general and detailed layouts in Figures 1 and 2, respectively), and with ENVISAT data since end 2003. The official status of IGS final ionospheric product was obtained in the IGS Governing Board meeting held at Nice, April 2003, after the presentation of the combined TEC maps performance in a dedicated report.

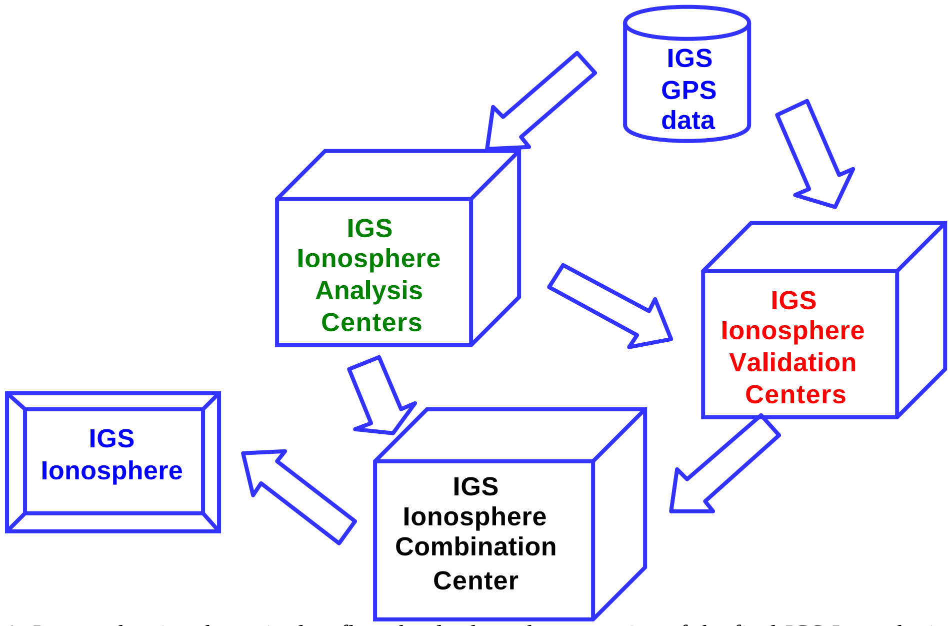

Figure 1: Layout showing the main data flow that leads to the generation of the final IGS Ionospheric product. IGS Final Ionosphere ionex files at ftp://cddisa.gsfc.nasa.gov/gps/products/ionex/. More details of the IGS final product, including download links at http://gage152.upc.es/~ionex3/igs_iono/igs_iono.html.

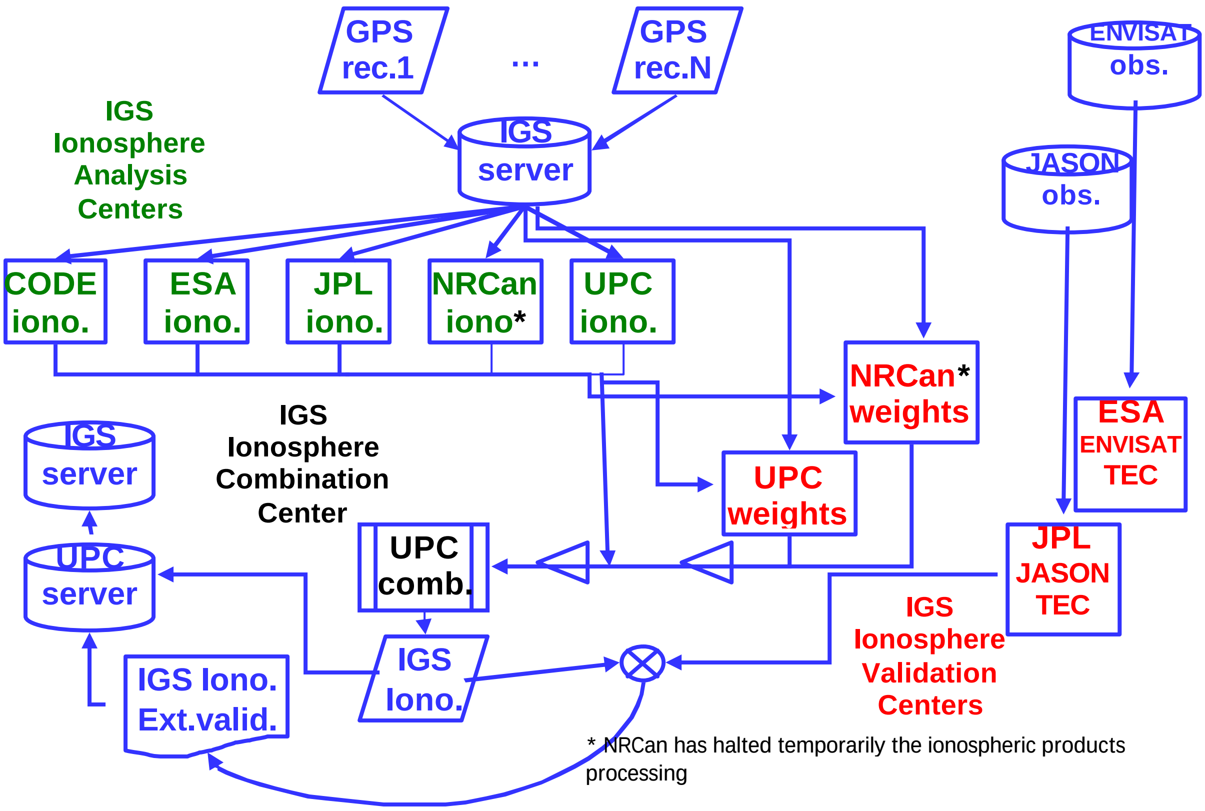

Figure 2: IGS Final Ionosphere flow chart detailing the previous layout.

The final IGS global maps, computed with a latency of about 11 days and with the resolution of 2 hours x 5 deg. x 2.5 deg. in UT x Longitude x Latitude, are stored in ionex format (Schaer et al., 1998[1]). They can be downloaded from the official server (CDDIS at GSFC/NASA[2], being the IGS and IAAC ionex files stored in the corresponding year and day subdirectories) and or from the combination center server, presently UPC[3]. Please refer to the IGS Central Bureau server[4] in order to have more complete information of the different available products and the corresponding directories structure in the IGS servers, such as CDDIS and IGN.

The generation of a rapid IGS product (with a latency of less than 24 hours) have been started in December 2003, by using an automatic software coded from scratch, and following the suggestion of the IGS GB during the meeting at Nice, in April 2003. The corresponding rapid combined global TEC maps (with the same resolution than the final ones, i.e. 2 hours x 5 deg. x 2.5 deg. in UT x Longitude x Latitude) can be accessed from the official IGS servers as well. There are also additional information such as comparison with JASON TEC (performed as well with a latency of less than 24 hours) and TEC movies. During the first year of generation of these rapid IGS maps, December 2003-December 2004, the combined product has been typically obtained by the afternoon (latencies of about 18-22 hours), initially with the two available ionosphere analysis centers (CODE and UPC). ESA and JPL made available its rapid products on a daily basis in January and February 2004, respectively (JPL made available its rapid product in a preliminary test performed during 5 days of December 2004 as well).

In this context the main purpose of this paper is to confirm the consolidation of the IGS Global Total Electron Content maps (IGTEC) as a final Ionosphere IGS product during the whole year 2003 (next section 2), and to show the performance of the rapid IGTECs during 2004, which generation was started in testing mode in December 2003, with latencies less than 24 hours (section 3). Finally the IGTEC validations with ENVISAT TEC, among the future goals and corresponding tasks, are going to be commented as well.

3. Final IGS Global TEC maps during 2003

As it has been mentioned in the Introduction section, the final IGTEC are computed with a resolution of 2 hours in UT, 5 degrees in longitude and 2.5 degrees in latitude. You can find one typical example in Figure 3 (during the day 347 of 2003, each 6 hours). At the same time the corresponding comparison with JASON TEC, used as an external source of direct vertical TEC measurements for validation, is provided in Figure 4.

1Description available at ftp://igscb.jpl.nasa.gov/pub/data/format/ionex1.pdf
2 ftp://cddis.gsfc.nasa.gov/gps/products/ionex/
3 ftp://gage.upc.es/pub/gps_data/GPS_IONO/cmpcmb/ where the IGS ionex file is contained in the corresponding YYDOY subdirectory, being YY the year and DOY the day.
4 http://igscb.jpl.nasa.gov/components/prods.html

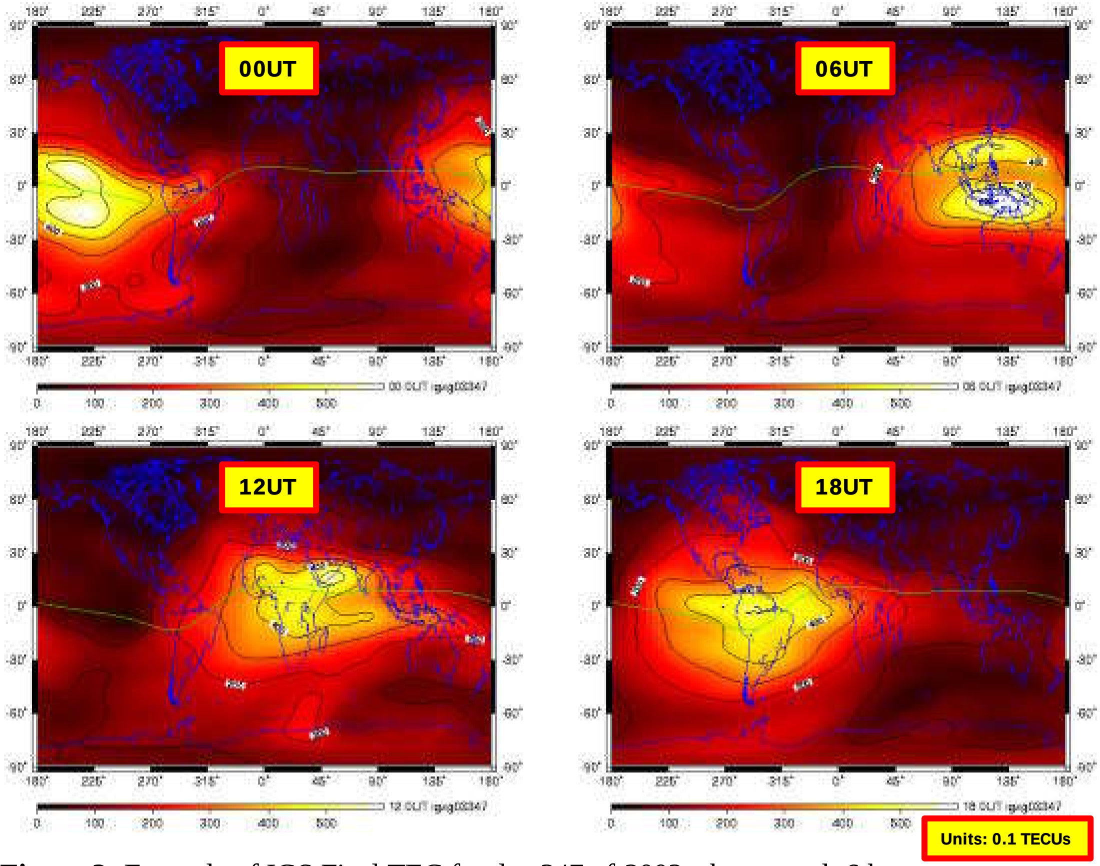

Figure 3: Example of IGS Final TEC for day 347 of 2003, shown each 6 hours.

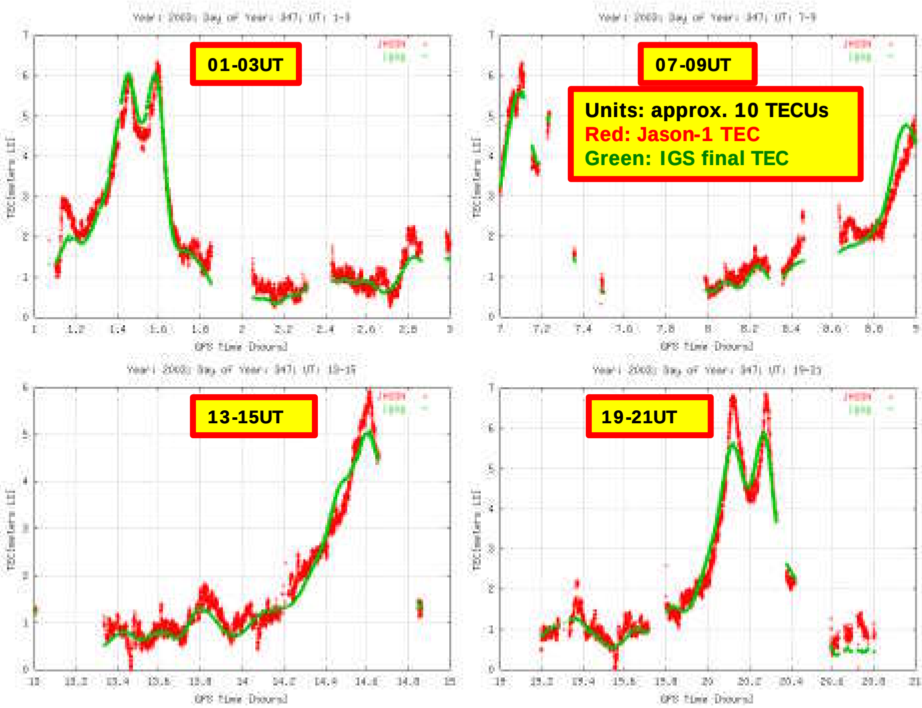

Figure 4: Example of comparison of IGS vs JASON TEC (day 347 of 2003, each 6 hours).

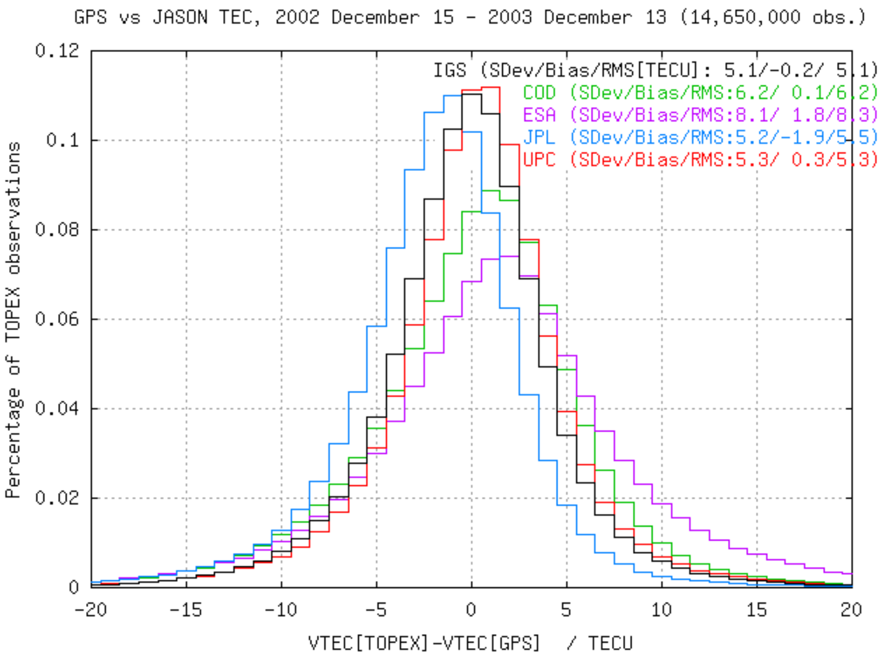

Figure 5: Final IGS TEC vs. JASON TEC in form of deviates histogram, comparing with the TEC performance of the different IAACs.

Indeed, as it is well known the JASON dual-frequency altimeter provides a direct and independent VTEC below its orbit (1300 km) and over the oceans (worst case for GPS). In Figure 5 the overall performance of the IGTEC comparing its prediction with the JASON VTEC measurements is shown during practically one year of data (15-Dec-2002 to 13-Dec-2003), with more than 14,000,000 of JASON observations compared. It can be seen than the IGS TEC (Std.Dev. 5.1 TECU) is slightly better or better than the IAACs TEC (Std.Dev. of 5.2, 5.3, 6.2, 8.1 TECU).

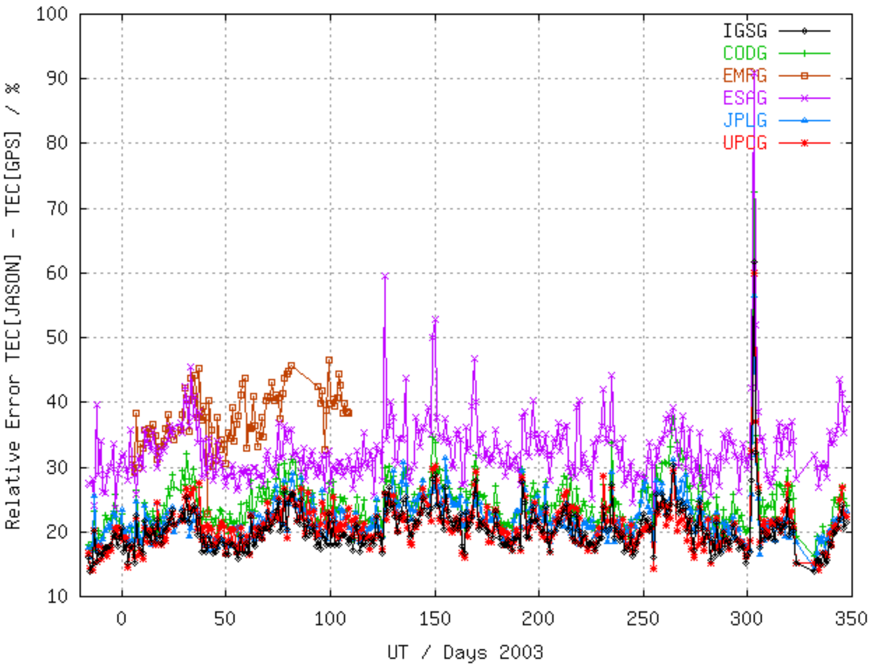

Figure 6: IGS TEC “Relative Error” vs. JASON (RMS normalized by the averaged TEC) during one year of data.

The temporal evolution of the performance of the IGS and IAACs "Relative Error" (RMS regarding to the JASON VTEC divided by the averaged JASON VTEC) is shown in Figure 6. It can be seen a typical daily relative error over the oceans of about 20% (15-25%). Sometimes large peaks appear coinciding with large geomagnetic storms, related to the present temporal resolution of 2 hours.

The performance dependence of the IGTEC regarding to the geomagnetic latitude is partially illustrated in Figures 7 and 8. The Standard Deviation of the JASON-IGS VTEC residuals is plotted showing that IGS presents a similar performance in the northern hemisphere compared to the best IAACs, slightly better performance at the equator, and slightly worst at southern latitudes. On the other hand the JASON-IGS TEC bias lower about 5 TECU around the equator (Figure 7) is compatible with the plasmaspheric component. The absolute bias reference is still unclear in JASON VTEC. Finally the IGS "Relative error" over the oceans is represented in Figure 8, which presents the following typical values:

- <15% at North mid and 20-25% at South mid latitudes.
- < 20% at ecuatorial latitudes.
- 20-30% at high latitudes.

Finally comparison of IGS and IAACs TECs with ENVISAT TEC (Standard Deviation and Bias) have been started during this period. It can be seen again the good performance of the combined final IGS product, as in the case of the previous altimeter comparisons with TOPEX and JASON. More performance details of the IGS final product (satellite and receiver DCBs, double dif. STEC, latency, with different data scarcity) can be found in the Iono-WG report presented in the IGS GB meeting at Nice in April 2003.

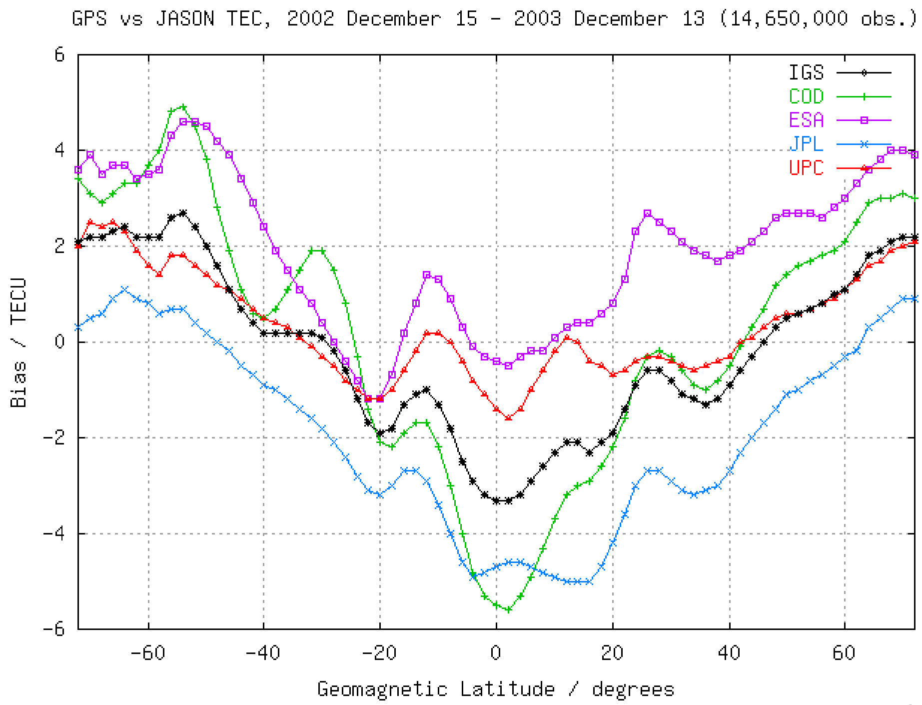

Figure 7: IGS TEC bias regarding to JASON TEC (JASON-IGS), represented as a function of the geomagnetic latitude.

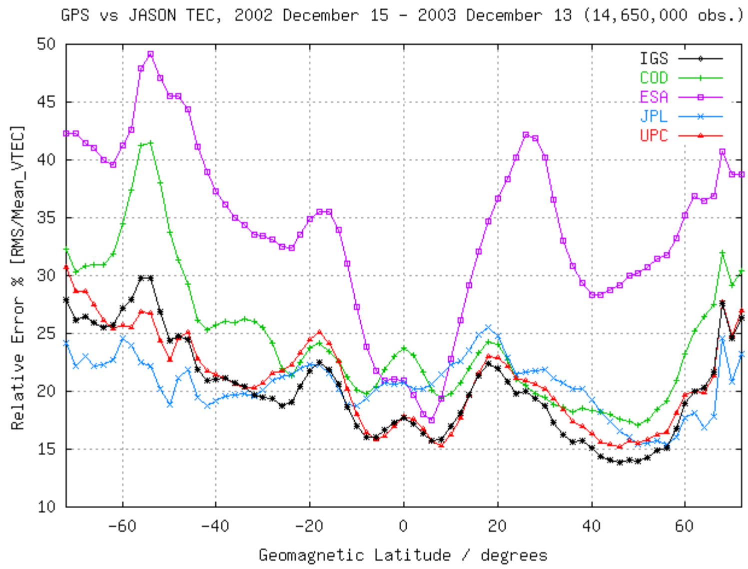

Figure 8: IGS TEC "Relative error" vs. JASON TEC plotted against the geomagnetic latitude.

4. First results of the Rapid IGS Global TEC maps

As was mentioned in the Introduction section, the generation of rapid IGS TEC maps was started in testing mode on 8 December 2003. A first performance metrics, by comparing the rapid and final performances, are given in Figure 9. It comprises the whole year 2004. We can see that the rapid IGS VTEC maps are in general only about 5-10% worse than the final ones. In future reports we will shown its performance in more detail.

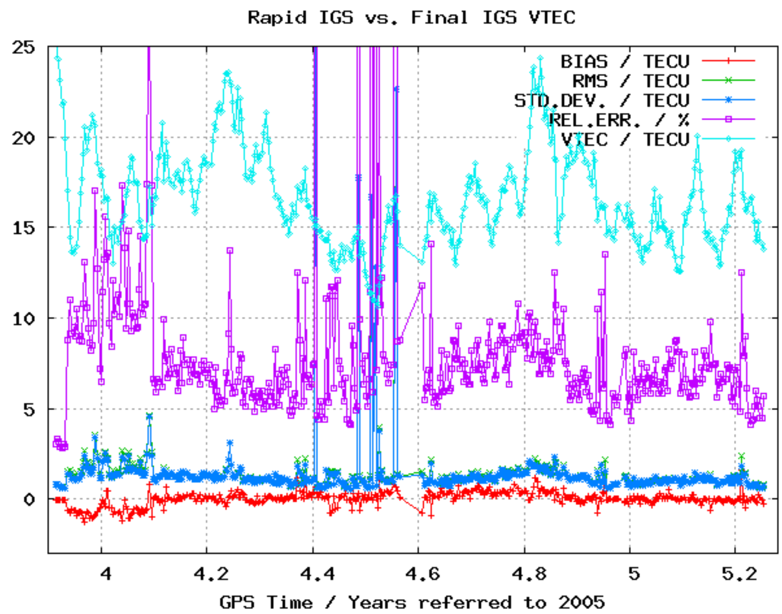

Figure 9: Global daily comparison of Rapid versus Final IGS VTEC maps. Their differences remain quite small since August 2004 (1-2 TECU, i.e. 5-10%), when several analysis centers fixed some occasional problems which had originated outliers in some regions during several days (NOTE: horizontal time represents the time in years referred to **2000**).

5. Conclusions and Future work.

After several improvements performed in the IAACs and IGS Ionosphere Map combination algorithms in 2003, the IGS final combination of TEC maps shows a good performance that is slightly better or even better than the individual IAAC maps that justified our efforts to start producing officially the final ionospheric product in April 2003. The rapid IGS TEC maps generation started in December 2003. These maps show a good accuracy during 2004 (only about 5-10% worse than the final maps) with a latency less than 24 hours (as opposed to 11 days of the final product).

The future activities of the IGS Ionosphere WG are going to be concentrated, among others, on:
(1) Consolidating the Rapid IGS Ionosphere product, in order to get official status.
(2) Augmenting the external data to be used for validation purposes: DORIS STEC data, provided by the International DORIS Service.

6. Acknowledgments

The author acknowledges to the IAACs colleagues for their continuous support and help in the activities of the Iono-WG. This acknowledgment is extended to all the people and agencies which make possible the International GPS Service.

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IGS LEO Working Group Annual Report 2003-2004

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Introduction

GPS / GNSS is likely to become one of the main tracking methods for future low satellites, due to its continuous tracking capability, and high precision. A constellation of low satellites with GPS receivers may enhance or perhaps even replace conventional Earth-based GPS tracking networks, offering specific advantages in tracking geometry, reduced receiver perturbations and de-correlation from Earth rotation parameters. The Low Earth Orbit Working Group of the IGS investigates the potential use of LEO GPS data for enhancing the product range of the IGS.

Technical issues in LEO GPS data processing

The merits of LEO GPS data can only be properly assessed if the LEO data is somehow included in an IGS-like process, after which it will be possible to analyze differences with processes that do not include LEO data. Before such comparative analysis is possible, IGS LEO still has to solve various technical problems.

First of all, the precision of the LEO antenna position information must become compatible to that of Earth-based tracking data, otherwise no relevant LEO contribution can be expected. Terrestrial stations have position uncertainties of a few mm, but in addition suffer from some data errors (e.g. uncertainties in troposphere) that the LEO data does not have. This means that for having LEO data of similar precision, the LEO antenna positions (hence the LEO orbits) must reach precision levels of about 1 cm RMS.

In order to assess the status of LEO POD and to assist in solving the remaining precision problems, IGS LEO organizes LEO orbit comparison campaigns. A JASON-1 campaign took place in 2003 and will be discussed further below. Also in support of advancing LEO POD, the IGS LEO Working Group has become closely linked to Working Group 1 of IAG Sub-Commission 1, which aims to study precise orbit determination from different tracking techniques in a broader sense than what would be possible for IGS LEO alone (see web link 2).

Secondly, the workloads involved with LEO processing must be kept within realistic limits. There are two basic approaches to including LEO GPS data in IGS-like processes:

1. Independent LEO POD: a precise LEO orbit is computed in a stand-alone process, after which it is used as a fixed geometrical reference in the POD process for GPS. The LEO GPS data is then processed in a similar way as Earth-based GPS tracking data.
2. Simultaneous LEO POD: the precise LEO orbit is estimated in the same process as the GPS orbits, contributing directly to the GPS orbits and clocks, ambiguities and Earth orientation parameters.

The first method is easier to implement: IGS could for instance make use of precise orbit solutions provided by the LEO missions themselves. However, this approach does not seem to offer the enhancements of the terrestrial reference frame realisation which form one of the main contributions that are expected from LEO GPS data (Boomkamp 2004a). The method of simultaneous solutions is therefore of more interest to IGS LEO. However, this leads to another technical problem: the higher frequency of LEO orbit perturbations require a much higher data rate (~30 seconds) for LEO POD process than what is typical for GPS POD (~5 minutes). This leads to a necessity for estimating high-rate clocks in the simultaneous POD approach, or it requires high-rate double difference processing. Both approaches result in a need for high-rate data processing for all GPS satellites and further station receivers in the solution, to the point that the data volume of a typical IGS process increases by one order of magnitude if one or more LEOs are included. So far, the process size of simultaneous solutions has been prohibitive for the IGS Analysis Centres that have LEO POD capability but alternative approaches are being developed.

JASON campaign

The CHAMP orbit campaign of 2002 made it clear that the Associate Analysis Centres with the strongest expertise in the area of LEO POD are typically not involved in routine IGS product generation, and vice versa. The CHAMP campaign served well as a platform to exchange information, but also indicated that integration of LEO GPS data processing in routine IGS product generation was still far away.

The release of the GPS data from JASON-1 lead to the second IGS LEO orbit campaign, in 2003. JASON-1 is of great interest to the space geodetic community, because it is the only LEO satellite that collocates four precise tracking systems (GPS, SLR, DORIS and radar altimetry) on a single satellite platform. At the same time JASON is orbiting three times higher than the more typical LEO height of ~400-600 km. This reduces its sensitivity to atmospheric perturbations and high-degree gravity perturbations, while allowing for much longer data passes over tracking stations on Earth. By consequence precise orbit determination for JASON is less complicated than for satellites like CHAMP or GRACE, making JASON-1 an attractive study object for IGS LEO Working Group.

For all details and results of the JASON orbit campaign, please refer to the IGS LEO website at (web link 1). Interesting results were in particular some systematic differences that could be observed between (e.g.) solutions based on a combination of DORIS and SLR data, solutions based on DORIS and GPS data, or solutions based on GPS data alone. Such systematic differences either indicate data modelling deficiencies for one of the tracking data types, or illustrate specific strengths and weaknesses of individual tracking data types. SLR data is highly precise, but has a poor geographic distribution. DORIS data has almost perfect global coverage, but is a range difference observation rather than an absolute range measurement. GPS has good global coverage, but only reaches its highest precision after much more complex processing than what is necessary for DORIS or SLR.

In particular, ambiguity resolution for the LEO satellites remains a difficult task. The high velocity of the LEO satellites quickly de-correlates successive phase observations to the point that conventional data cleaning methods either miss too many cycle-slips, or detect cycle slips where there are none. During the course of 2003 – 2004, various Associated Analysis Centres have published methods for LEO ambiguity resolution or LEO GPS processing in general, for instance (Svehla 2003) and (Hugentobler et al., 2003).

The current conclusion must be that although the technical difficulties in LEO POD are substantial, clear progress can be observed. For JASON, some specialist LEO centres can already demonstrate precision levels around the general target of ~1 cm (Luthcke et al., 2003). It can be expected that it is only a matter of time before a relevant number of IGS Analysis Centres reaches adequate LEO POD capability to support the IGS LEO analysis objectives.

Processing capacity

The increased data rate for simultaneous solutions for GPS and LEO results in a need for processing much larger data volumes than before. Various other developments in IGS also contribute to a need for "Bigger, Better, Faster POD", which was therefore the topic of the Session on Orbit Determination during the Berne Workshop (Boomkamp & Koenig, 2004). Improvements in computer hardware have been so remarkably stable over time, that a credible prediction can be made of future computing power. The anticipated trends in IGS processing, notably the increase in data rate for including high-rate LEO data, may well collide with the limits of available computer hardware. It is therefore necessary to look for new, more efficient algorithms that can handle larger data volumes without requiring proportionally more computer power.

An example of a new algorithm was presented in Berne where undifferenced data at the low rate of 300 second intervals was used for all GPS satellites, LEO satellites and ground stations, while 30 second high-rate double differenced observations are added only for the LEO POD. The double differenced observations ensure sufficient observability of the high-frequent LEO orbital perturbations, while the low-rate data allows an IGS-like process for GPS in which the LEO contributes as any other tracking station. Some changes in the way in which the double-differenced normal equations are accumulated allow for an efficient process that does not lead to a prohibitive increase of CPU time. For more details, please refer to (Boomkamp, 2004a).

Status of LEO processing at the IGS Analysis Centres

Four of the present IGS Analysis Centres are in the process of developing LEO GPS processing: GFZ, JPL, CODE and ESOC. The first two centres have advanced LEO capabilities due to their role in the CHAMP and GRACE missions, but the other two centres have been catching up and are now in a position to also contribute to the analysis in a relevant way.

According to the IGS LEO Charter, a first objective will be to demonstrate a positive impact of the LEO GPS data on IGS-like products generated by a single Analysis Centre. Some initial publications in this area are now available (e.g. Zhu et al, 2004). With the improvements in technical areas and the arrival of more LEO GPS data in the immediate future (GRACE, SWARM) it can be anticipated that sufficient material will be accumulated to build a convincing case, either demonstrating that the inclusion of LEO data in IGS processing brings unique improvements, or showing that the benefits of LEO GPS data do not justify the substantial effort.

Assuming a positive outcome of this analysis, the number of four Analysis Centres with LEO capabilities will be sufficient to allow – one day – experimental inclusion of LEO data in IGS processing, in parallel to the nominal processing. It is clear that the workload involved with such a demonstration will be substantial, because the LEO processing will multiply the nominal IGS processing load with a substantial factor. In addition, such a demonstration will require additional work from the IGS Analysis Coordinator. This means that, even though such a campaign forms a necessary step towards achieving the Working Group objectives, thorough preparation will be necessary to justify the substantial effort.

Conclusions

The technical difficulties in including LEO GPS data in an IGS-like process are substantial, but the past two years have shown important progress both in LEO processing precision, and in methods for handling the large LEO data volumes in a practical way.

The assets available to the IGS LEO Working Group are modest and essentially consist of voluntary analysis contributions from the Associated Analysis Centres. Given the complexity of the technical issues that are being solved, the speed of progress over the past two years is satisfactory. Great care will be taken in making optimal use of the limited time and resources that can be made available to IGS LEO analysis.

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Web links

1.	IGS LEO website	nng.esoc.esa.de/gps/igsleo.html
2.	IAG Working Group 1	nng.esoc.esa.de/iag_wg111.html
3.	COSPAR 2004 publications online	www.sciencedirect.com/science
4.	Berne Workshop	www.igsws2004.unibe.ch

International GLONASS Service Pilot Project

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Robert Weber, University of Technology, Vienna, Austria

GLONASS Constellation Status

Russia launched three new GLONASS satellites in December 2003 and three more in December 2004. Eight healthy satellites were generally available in 2003 and 10-11 satellites in 2004.

IGLOS Tracking Network

The International GLONASS Service Pilot Project (IGLOS) has maintained a stable tracking network of 45 or more tracking stations. There is a large cluster of stations in Europe, and geographically distributed but sparse coverage in other parts of the world (see Figure 1.) In addition, the International Laser Ranging Service continued tracking three of the operational satellites during the period. Of the 51 receivers at 49 sites operating in mid-2004, 35 receivers were Javad or Topcon Positioning Systems and the rest were Ashtech Z18s. These were all dual-frequency, combined GPS/GLONASS receivers.

Based on 10 active GLONASS satellites and all GPS satellites at an elevation cutoff angle of 5 degrees, a combined total of up to 16 satellites were visible for part of the day from most locations. Figures 2a and 2b illustrate the enhanced satellite visibility provided by the GLONASS constellation in February 2004 when the GLONASS satellites are combined with the GPS satellites in view in Thule, Greenland (latitude 76.5º N) and Kourou, French Guyana (latitude 5.3º N).

Precise Orbits and Other Products

In June 2003, the University of Berne's CODE Analysis Center began producing GLONASS orbits as part of its routine IGS orbit processing. CODE generates final, rapid and ultra-rapid orbits for GLONASS at the same time it generates GPS orbits. This greatly reduced the latency of the IGS GLONASS products. CODE uses GLONASS and GPS observations in its Earth Orientation Parameter estimates, weekly SINEX tracking station coordinate computations, and tropospheric and ionospheric products. BKG and ESA continued to produce precise GLONASS orbits and significantly shortened the time delays for submitting the orbits.

The major accomplishment for the year 2004 was the complete merger of the IGLOS tracking stations, tracking data and precise orbits into the mainstream IGS operations. The separate IGLOSmail system was terminated. Product file and report names were modified slightly to conform to the GPS conventions. Beginning the week of December 5-11, 2004 (GPS Week 1300), the combination solution for the GLONASS final products was incorporated into the standard data processing by the IGS Analysis Coordinator at GFZ in Potsdam. The combined orbits are based on the CODE, BKG and ESA precise orbits. Satellite laser ranging (SLR) orbits are computed by the Russian Mission Control Center (MCC) for the few GLONASS satellites with available data. These orbits are used as a quality control check, but are not incorporated in the combined GLONASS orbits. There is about a 2-3 week time lag between the date of the last IGLOS Analysis Center orbits submitted to GFZ and the release of the combined orbits. Orbit accuracy is estimated to be at the ± 10 cm level (see Figure 3).

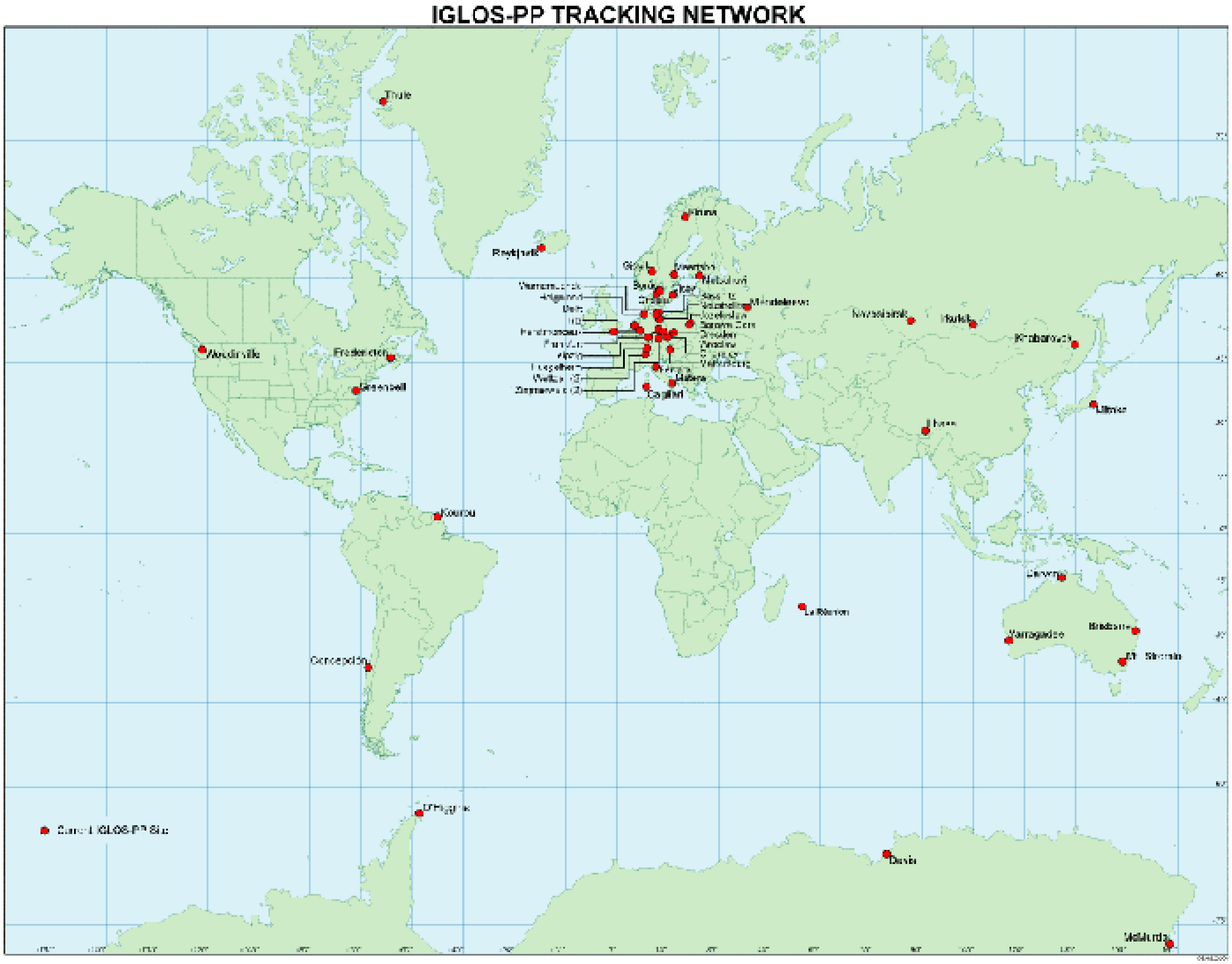

Figure 1. IGLOS tracking stations (Aug. 2004).

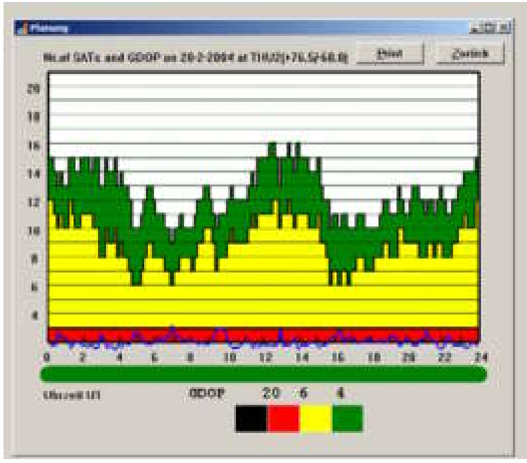

Figure 2a. Satellite visibility and GDOP in Thule, Greenland (yellow/lower area=GPS, green/upper area=GLONASS, blue trace= GDOP.)

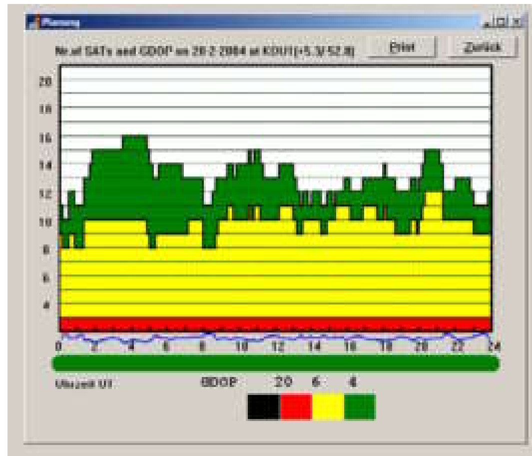

Figure 2b. Satellite visibility and GDOP in Kourou, French Guyana (yellow/lower area=GPS, green/upper area=GLONASS, blue trace= GDOP.)

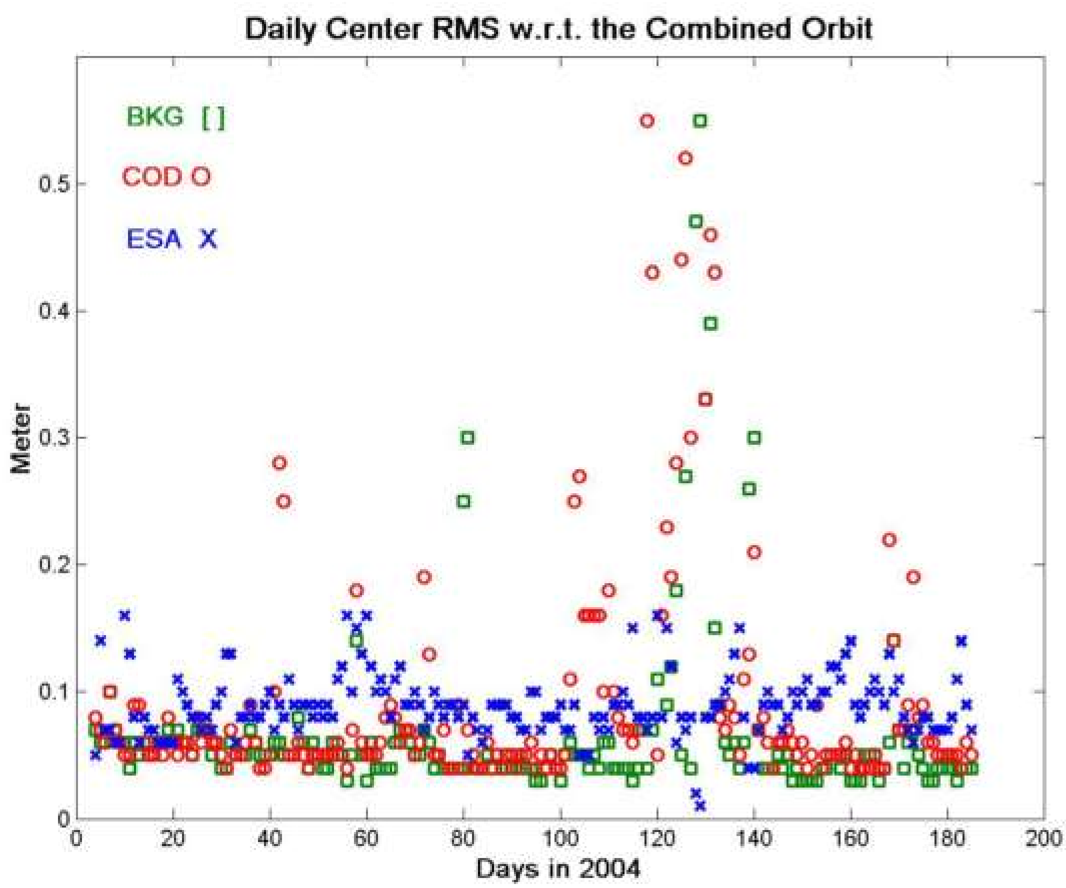

Figure 3. Daily RMS differences between Analysis Center satellite orbit solutions and combination orbit solutions for the first six months of 2004.

IGS Real-time Working Group Technical Report for 2003-2004

Mark Caissy

Natural Resources Canada
Chair IGS Real-time Working Group

The goal of the IGS real-time working group is to develop infrastructure and processes for the delivery of real-time data to analysis centers and the dissemination of real-time products to users. The working group's direction for the 2003-2004 timeframe was set at the Ottawa IGS workshop in the spring of 2002. At this workshop the architecture for a prototype real-time network was adopted. During 2003-2004 the working group's efforts concentrated on building the prototype using the adopted architecture. This report describes the architecture and recounts the progress made in building the prototype network during the 2003-2004 timeframe.

1. Prototype Architecture

A key principle of the architecture was that existing real-time networks would continue to operate autonomously. The design centered on the integration of autonomous networks into a shared network for the exchange of data and products. Additionally, all major elements of the IGS were included in the architecture; therefore regional networks, global data centers and analysis centers were to be integrated in the prototype.

Only those elements considered essential for the purpose of testing the suitability of the architecture were included in the original prototype. These elements were:

- Operation management considerations including:
  - ✓ Change management
  - ✓ Performance characterization

- Data transport protocol

- Data packet structure including observation types

Additionally a number of software tools were to be developed that would enable agencies to play an active role within the real-time IGS. The developed tools would meet the data management and data distribution requirements at both tracking stations and data centers.

These essential elements are described in the sections that follow.

1.1 Operation Management Considerations

In a real-time processing environment, particularly one in which autonomous networks share data in real-time, it is essential that changes made at a tracking station be conveyed to users in real-time. This is essential, particularly if the changes are of a nature that could bias a real-time product. An example is a change in the height of an antenna at a tracking station. To address this the working group created the Issue of Data Station (IODS) observation type. It was designed to indicate a change in the station's state. Real-time users of the data are to monitor for a change in state of the IODS and when a change occurs data from this station must not be used until the change has been accounted for in the real-time user's processing environment. It is the responsibility of real-time station operators to increment the IODS, alerting the real-time user community that a change has occurred.

The architecture was to be tested using the following performance characteristics:

- The percentage of observations received
- The average delay of observations

From a network performance standpoint the following characteristics were considered desirable but not required for assessment of the early prototype.

- Station data quality statistics
- Global network statistics (satellite specific)

1.2 Transport Protocol

UDP was chosen rather than TCP as the transport protocol. Although UDP is a connectionless protocol several members of the working group had considerable experience using UDP for real-time data delivery and were convinced that there were important advantages for true real-time applications. The primary advantage is that UDP typically delivers more data with lower latencies than TCP. However the disadvantage of UDP is that data packets are often lost when communication networks are congested. It was felt that the deficiency (sacrificing data packets) in using the UDP protocol could be overcome without compromising the purpose for which the real-time streams will be used.

1.3 Data Packet Structure

A specific data packet structure was designed that allows any type of data to be moved in real-time within the network. This is a particularly important design since it allows the inclusion of data from any discipline. Each data packet contains a uniform 11-byte header as follows:

TYPE	VARIABLE	MEANING
unsigned short	rec_id	indicates the data type
unsigned short	sta_id	unique station id
unsigned long	GPSTime	data time tag in seconds past 6-Jan-1980
unsigned short	num_bytes	number of bytes in this message
unsigned char	IODS	station configuration flag

The observation data then follows the header. Four basic observation types were defined. They were:

1. GPS observation data
2. GPS satellite ephemeredes
3. Meteorological data
4. Issue of Data-Station (IODS)

Assembling these essential elements into what would become the IGS Prototype Real-time Network was the focus and the following section describes the results of that effort.

2. Prototype Network

During the 2003-2004 time frame considerable progress was made towards building the prototype network. By the spring of 2003 the network began to take shape and progress was reported in a poster [1] presented at the EGU meeting in Nice. Figure 1 illustrates how the network consisted of three real-time tracking stations, AOML (Miami Florida) managed by NGS, HLFX (Halifax Nova Scotia) managed by NRCan and Dunedin (New Zealand) managed by GFZ. IGN served as a global data center and both NRCan and GFZ served as real-time analysis centers.

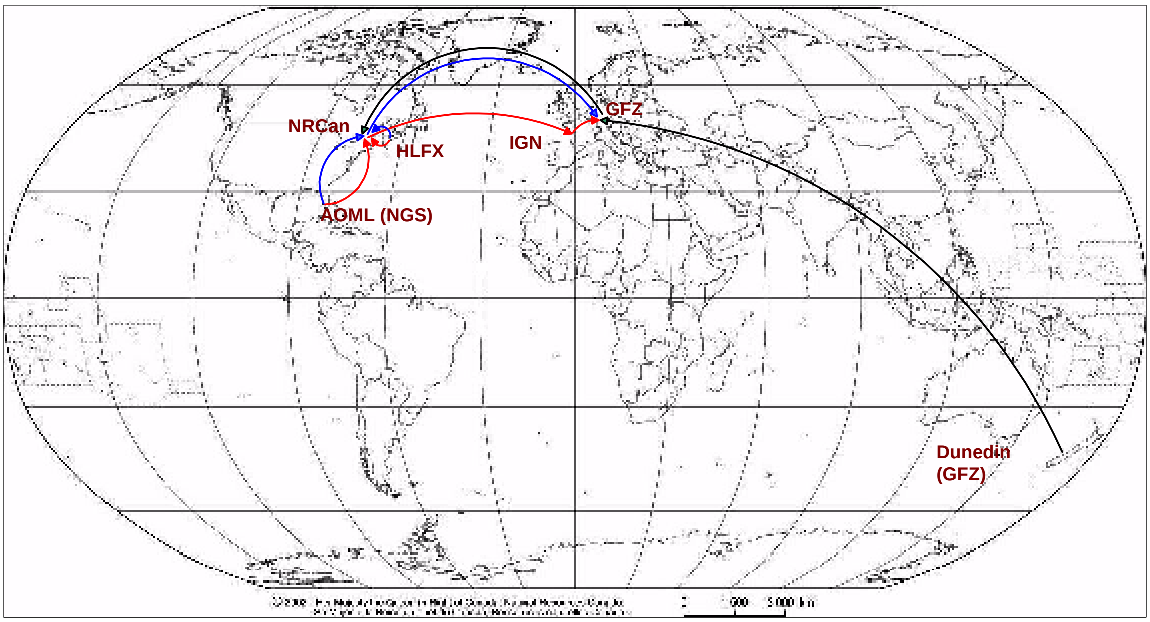

Figure 1 *Prototype Network Spring 2003*

2.1 Performance Metrics

Two metrics were used to assess the performance of the prototype network.

1. The number of observations received in percent.
2. The average delay of observations in seconds.

The percentage of observations received was computed at 15-minute intervals within which 900 one-second epochs were expected. Table 1 contains the average of all 15-minute samples for the end points; GFZ for AOML and HLFX and NRCan for Dunedin data.

Table 1: *Percentage of Real-Time Observations Received*

	Average 15 minute samples(%)
AOML to GFZ via NRCan	99.5%
AOML to GFZ via NRCan/IGN	94.9%
HLFX to GFZ via NRCan	99.1%
HLFX to GFZ via NRCan/IGN	95.2%
Dunedin to NRCan via GFZ	98.9%

The average delay was computed at 15-minute intervals. The delays were computed by differencing system-time with the GPS data epoch-time. System time was maintained across the network using NTP timeservers synced to GPS time. Table 2 contains the average of all 15-minute samples for the end points, again GFZ for AOML and HLFX, and NRCan for Dunedin data. The Dunedin delays were considerably longer because of additional processing at the site. Each station had its own characteristic delay-signature owing to its uniqueness.

Table 2: *Real-Time Observation Delay (sec.)*

	Average 15-minute samples (seconds)
AOML to GFZ via NRCan	.31
AOML to GFZ via NRCan/IGN	.35
HLFX to GFZ via NRCan	.33
HLFX to GFZ via NRCan/IGN	.34
Dunedin to NRCan via GFZ	1.5

The results were very encouraging. The early prototype network had been constructed using the essential elements described in sections 1.1 to 1.3. Data that originated from two separate and autonomous networks was being shared and a global data center together with two analysis centers were integrated. It was concluded that the architecture was sound, including the use of UDP for the data delivery protocol. The next steps would involve enhancing the network.

2.2 Growth of the Prototype Network

By the end of 2003 a web site [2] had been established where visitors could view the extent of the network as well as the performance. By this time the network had grown to 10 stations with the goal of expanding the network to 20+ stations before the Berne meeting. Figure 2 illustrates the network proposed at the time. It consisted of 26 stations with contributions from 9 agencies. [Red (NRCan/NGS/IBGE), light blue (JPL/Delft), dark blue (ESOC), yellow (GFZ), light green (BKG) and light purple (GA)]

At the Berne workshop in the spring of 2004, it was shown that the current prototype network consisted of 23 stations with contributions from 7 agencies. The oral and poster sessions demonstrated the interests in and current status of real-time activities among IGS agencies, including a poster [3] by the real-time working group.

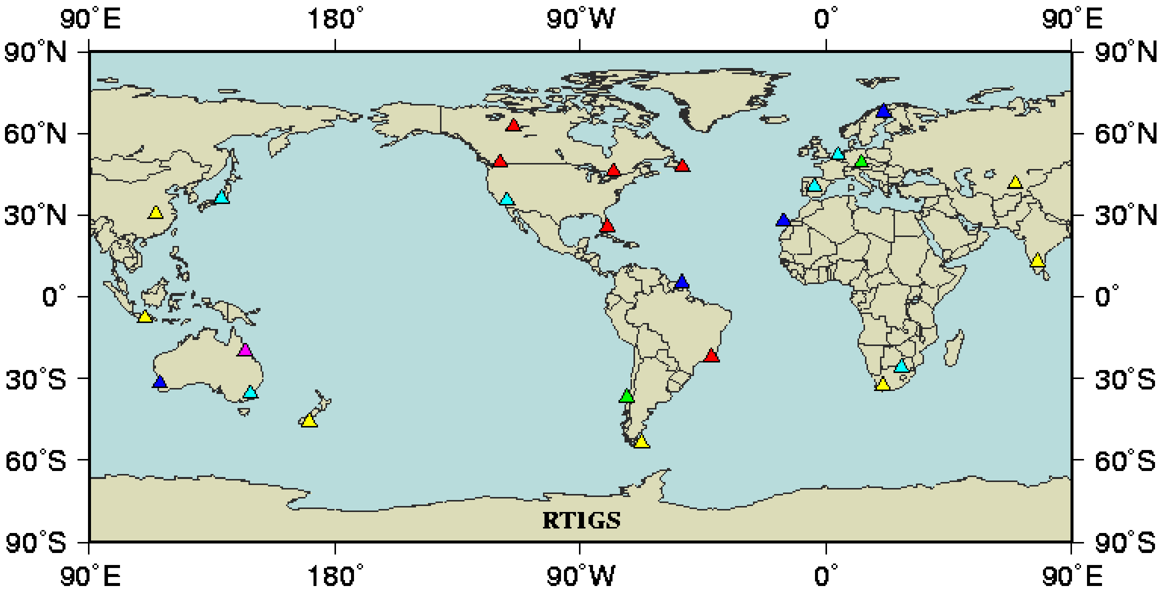

Figure 3 *Proposed 26 Station Network Spring 2004*

By the end of 2004 the following activities were underway:

- Progress was being made towards the exchange of data between the IGS real-time model and the NTRIP model.

- Station software tools had been deployed at IBGE, NRL and IEN enabling these agencies to contribute real-time station data.

- UCAR-COSMIC had installed the udpRelay application and were receiving a number of IGS real-time streams.

3. Future Activities

The following activities were the focus in 2005

- Expanding the real-time network to include stations from Geoscience Australia and additional stations from ESA
- Increasing product generation activities particularly within the timing and atmospheric science communities
- Installing real-time data distribution and archival applications at global data centers
- Increasing reliability of data available for near-real-time and real-time applications
- Increasing characterization of network performance
- Increasing redundancy in data availability from around of the globe

References

[1] Caissy, M., R. Galas, L. Daniel, K. Macleod, J. Dawson, M. Chin (2003) Real-time Data Distribution Within The IGS – Prototype Network and Performance Characteristics, EGU Nice, France.

[2] http:// igsdr.geod.nrcan.gc.ca/ Username*:operator* Password: *4IGSDR2use*

[3] Macleod, K, M. Caissy, R. Fong, B. Twilley, J.P. Bartolome, C. Garcia-Martinez, R. Galas, R. Muellerschoen (2004) Real-time IGS Protocol, Formats and Software Tools, IGS Symposium and Workshop Bern, Switzerland.

IGS Data Center Working Group

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Introduction

The IGS Governing Board recommended the formation of a working group to focus on data center issues at its December 2001 meeting in San Francisco. This working group hopes to tackle many of the problems facing the IGS data centers as well as develop new ideas to aid users both internal and external to the IGS. The IGS Data Center Working Group (DCWG) will address issues relevant to effective operation of all IGS data centers, operational, regional, and global. Some of these issues include:

- effective data flow
- backup of the operational data flow
- security issues at data centers
- consistency of data holdings among data centers
- timely archive and dissemination of data as the IGS moves into a real-time mode for selected products

A web site has been developed (*http://cddis.gsfc.nasa.gov/igsdc*) for the working group. This website contains the charter and list of members as well as information about current and planned activities. A mailing list (*igs-dcwg@igscb.jpl.nasa.gov*) is maintained at the IGS Central Bureau since June 2002 for working group communications.

Recent Activities

In 2004, a Charter for IGS Data Centers was completed and submitted to the Central Bureau for reference by the IGS Terms of Reference. This document can be used by any group wishing to join the IGS as a global, regional, or operational data center. In fact, the Korean Astronomy and Space Science Institute (KASI) submitted a proposal to the IGS in 2003 for a new global data center. The DCWG has worked with KASI staff in establishing this new data center, which will be a valued addition to the archiving activities of the IGS. KASI plans to test operations through 2005 with hopes to become a fully operational GDC in January 2006.

The DCWG is also working with the Real Time Working Group (RTWG) on the transmission of real-time GNSS data to the IGS data centers. At this time, it is unclear how the data centers can contribute to the real-time activity. Two possibilities are under consideration: acting as a relay of data to the actual real-time data users or using relaying as a way of transmitting high-rate data for archive at the IGS data centers. The later activity could replace the current file-oriented transmission of high-rate data.

The working group coordinated a "latest" directory structure at all IGS GDCs. This directory provides expert/routine users with the latest versions (several days or weeks) of IGS ultra-rapid, rapid, and final products. For example, at the CDDIS these products can easily be located in subdirectories by product type of *ftp://cddis.gsfc.nasa.gov/pub/gps/products/latest*.

Another area of discussion over the past two years concerned the type of compression utilized within the IGS. Since the start of the IGS Test Campaign in 1992, the data centers have used UNIX (LZW) compression (all files have a .Z extension). Users, particularly the IGS Analysis Centers, have coded this type of compression into their automated procedures that retrieve and analyze GNSS data. Members felt the working group should investigate other types of compression (e.g., gzip). Ultimately, the group must interface with users to determine if a switch to another type of compression brings advantages in data storage, ease of use, and future expansion. Cross-platform compatibility issues and conversion of the older data to any new compression format must be addressed as well.

Meetings

A meeting of the working group was held in March 2004 at the IGS Symposium and Technical Workshop in Berne Switzerland. Two major topics were discussed, the long-term archive of raw data and the management of replacement data. Maintaining an archive of raw data is useful for two major reasons. Errors in RINEX conversion have occurred and require the raw data to correct. Since a majority of sites provide data to the IGS at a 30-second sampling rate, if higher rate data are required (i.e., to study past or silent earthquakes), raw data would need to be used. The working group recommended that operational data centers continue to be the source of raw GNSS data and should maintain an archive indefinitely; these data do not need to be generally accessible to the user community but should be available to users upon request.

The second major topic of discussion at the March 2004 meeting concerned how to manage replacement, retracted, or data transmitted with a large (e.g., months) delay. Discussion touched on what type of problem/change requires a replacement as well as how to notify users of these data updates. Currently, data replacement messages are sent to subscribers of the IGSStation exploder. While this method notifies subscribed users of problem data, an archived list of these data and replacement information would aid users in the long run. The group recommended circulating ideas for possible solutions and then developing a plan for future discussion.

IGS GNSS Working Group

2003-2004 IGS Technical Report

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Introduction

Recognizing the importance of the upcoming new European satellite navigation system (GALILEO) and of the modernization programs planned for GPS and GLONASS the IGS decided in December 2002 to set up a GNSS-Working Group. A major goal of this WG is to prepare a consolidated feedback to GNSS system engineering based on relevant IGS experience of providing highest accuracy products for the existing systems. Special emphasis should be laid on calibration characterization issues such as the role of SLR for orbit determination, estimation of inter-system and inter-frequency biases, clock and orbit prediction as well as reference frame definition and realization. End of 2003 these items were addressed by a list of recommendations from the IGS-WG to the entities involved in GALILEO System Design as well as GPS and GLONASS modernization. The recommendations mainly concerning satellite orbit determination and realization of the ITRS are listed below. The full list can be obtained from the Working Groups Web-Page.

1. The IGS asks for a proper calibration of GALILEO, GLONASS and modernized GPS satellite antennas (before launch) and for providing that data to the scientific community.
2. It is encouraged to put laser retro-reflectors on all GNSS satellites.
3. In order to collocate the GALILEO Reference Frame (GRF) to ITRF the IGS asks for a proper calibration of GRF Reference Station antennas and for providing that data to the scientific community.
4. Cross-link measurements between the GNSS satellites would be a very important measurement type with inestimable impact on all derived products.
5. The IGS GNSS WG should be recognized as an interface for information exchange and for stimulating cooperation between IGS and entities involved in the technical set up of GALILEO as well as modernized GPS and GLONASS.

Link to IAG-Commissions

After the IUGG Meeting in Sapporo 2003 the IAG Commission I on ‘Reference Frames’ decided to set up a Study Group entitled ‘Use of GNSS for Reference Frames’. Goal is to evaluate and support the use of Global Navigation Satellite Systems for the definition and densification of the International Terrestrial Reference Frame (ITRF). According to the new statutes of IAG it has been agreed that the IGS-GNSS WG and IAG IC-SG1.2 should be closely coordinated. Furthermore the whole group is closely linked to IAG Commission IV on ‘Positioning & Applications’. The membership list has been broadened according to the new topics. One of the overlapping goals clearly is how to take advantage of the IGS product suite for the definition and densification of the ITRF.

Coordination and Interface

To coordinate the scientific and organisational work several meetings of the Working Group took place in 2003/2004:

- Open WG-Meeting during ION 2003, Portland
- Open WG/SG-Meeting during IGS Workshop & Symposium, March 2004, Berne
- Meeting of WG/SG members with Galileo Project Team at ESOC (Darmstadt) (June 29th,2004)
- Meeting SC-, WG- and SG-chairs of Commission IV during ION 2004

As one of the outcomes of the IGS Workshop and Symposium in Berne in March 2004 the following directions affecting the Working Groups future activities are worth mentioning:

The IGS should start as soon as possible the discussion with receiver manufacturers to explore an optimal set of signals to be tracked by GNSS receivers.

Revise all format standards used by IGS entities (to transfer tracking data, orbit & clock information, as well as derived products) to properly exploit all opportunities offered by Next Generation Satellite System signals.

The WG Terms of Reference as well as meeting reports can be accessed via

http://mars.hg.tuwien.ac.at/Research/SatelliteTechniques/GNSS_WG_IGS/gnss_wg_igs.html
and
http://www.gps.oma.be/IAG-study-group/workprogram.php

Future Activities

In the near future the Working Group will try to explore an optimal set of signals (from GPS, Galileo, Glonass) to be tracked by future geodetic GNSS receivers. Furthermore the interaction with entities involved in the technical set up of modernized GPS (GPS III) and modernized GLONASS should be intensified, preferably to a level similar to the current interaction with the Galileo project team.

A study under preparation should reflect opportunities of the upcoming modernization of the Global Navigation Satellite Systems with respect to the work of IGS Analysis Centers as well as other IGS Working Groups.
In addition, based on the agreed reference network design, we will investigate the quality of the tie and anticipated time evolution of the GALILEO Reference Frame with the ITRF. Furthermore the group will concentrate on expected synergies using a real GNSS observation network covering three satellite navigation systems for reference frame maintenance.

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AFREF – A Continental Reference Frame for Africa 2003-2005

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Introduction

During the period 2003 to 2005, the establishment of a continental geodetic reference frame for Africa within the AFREF project has shown slow but steady progress. Although few new permanent GNSS stations have been installed in Africa, the concept of AFREF and its goals and objectives have been well publicized and have gained acceptance and support from a number of organisations within Africa and internationally. Much of the publicity for the project within Africa has been driven by the CODI-GEO AFREF Steering Committee while the IGS Central Bureau has made the project widely known within the international geodetic community through presentations at conferences and meetings.

Objectives of AFREF

The objectives of AFREF were established in 2002 and have largely remained the same since then namely:

- To define the continental reference system of Africa. Establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-d reference networks fully consistent and homogeneous with the global reference frame of the ITRF;
- To realize a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project activities;
- To establish continuous, permanent GPS stations such that each nation or each user has free access to and is, at most, 1000km from such stations;
- To provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks, and numerous applications, with readily available technology;
- To understand the necessary geodetic requirements of participating national and international agencies; and
- To assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

Acceptance of AFREF between 2003 and 2005

In broad terms the "Windhoek Declaration of an African Geodetic Reference Frame (AFREF)" was a commitment made in December 2002 by 8 East and Southern African countries to;

- Support the AFREF project;
- Publicize and promote the project within their respective Governments and appropriate international organizations

and that;

- The UN Economic Commission for Africa (UNECA) should accept the principles and concepts of AFREF and that these be accepted by the UNECA Committee on Development Information (CODI) for implementation;
- The UN Office for Outer Space Affairs (UNOOSA) be requested to support the project and;
- The IAG and its service organization, the IGS, be requested to continue to support the project and assist with its implementation.

On consideration of the above, most of these principles have or are in the process of being met. The "Windhoek Declaration" was accepted as a formal document by the UN CODI in May 2003 and AFREF became a formal project within the CODI-Geographical Information (CODI-GEO) sub-committee of CODI. In August 2004 CODI-GEO established a formal AFREF Working Group whose structure was formalized in April 2005 at the International Federation of Surveyors (FIG) Working Week in Cairo. The structure of working group is shown in Fig 1.

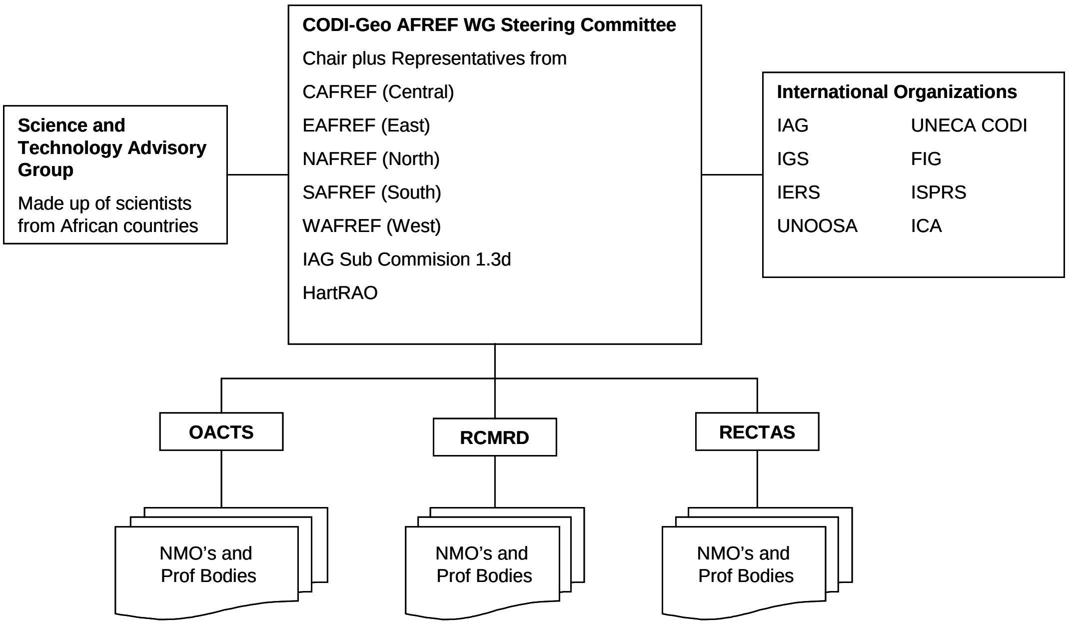

Figure 1 Organizational structure of CODI-GEO Working Group on AFREF

The structure shown in Figure 2 reflects the broad concept of AFREF that:

- it is to be designed, managed and executed from within Africa under the guidance of the AFREF Steering Committee;
- it is to be organized on a regional basis mainly through the regional surveying and mapping centres, namely the l'Organisation Africaine de Cartographie et de Teledetection (OACT) in North Africa, the Regional Centre for Training in Aerospace Surveys (RECTAS) in West Africa and the Regional Centre for Mapping of Resources for Development (RCMRD) in East and Southern Africa;
- it is to be executed at the national level by the National Mapping Organizations (NMOs); and
- technical expertise and support will come from the international geodetic community as well as the AFREF Science and Technology Advisory Group. The role of the Science and Technology Group will be largely to advise on matters such as telecommunication, power supply and general scientific aspects unique to Africa.

Publicity and Garnering of Support for AFREF

A number of papers and reports on AFREF have been presented at international conferences, workshops and meetings between 2003 and 2005 including;

- the presentation of progress reports to the IAG in Nice in April 2004;
- the organization of an AFREF workshop in Nairobi in October 2004 during the African Association of Remote Sensing of the Environment conference;
- the presentation of three papers at the FIG Working Week in Cairo in April 2005;
- the presentation of reports to UN ECA CODI in Addis Ababa in April 2005 ;
- the presentation of one paper at the IAG Scientific Assembly in Cairns in August 2005;
- the presentation of one paper and display of IGS material with an AFREF theme at the AfricaGIS Conference in Pretoria in November 2005;
- the presentation of reports to UNOOSA in Dec 2003 and Dec 2005 and;
- the publication of a number of articles on AFREF in appropriate journals and interest magazines.

In an effort to gain support for the project, a “Call for Participation” and letters of intent were widely circulated and published in October 2005 on a website (http://geoinfo.uneca.org/afref/) hosted by the UNECA. The “Call for Participation” (CfP) and letters of intent were seen as mechanisms for organisations to commit to and support the project either by offering technical and scientific support and equipment or funds. Up until the end of December 2005, 14 countries, universities or commercial enterprises responded to the CfP and have committed to support the project.

Conclusion

Although progress has been slow with the installation of continuously operating GNSS reference stations, a great deal of effort has been placed on extending publicity and gaining support for the project. It is felt that, with the ground work that has been done in broadening the sphere of interest and commitment to the project, the next few years will see a rapid increase in the number of reference stations installed throughout Africa in pursuance of the ideals and objectives of AFREF and the IGS.